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DESCRIPTION OF THE DRES PRACTICE MINE HARDWARE (U)

by

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Military Enginnering Section

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Abstract

The Ordnance Detection Group (ODG) of the Defence Research Establishment Suffield (DRES) has designed an electronically fuzed landmine to be used during training exercises. A description of the hardware within the Practice Mine is given in this report.

Contents

List of Figures

List of Tables

1. Introduction

The development of scatterable mines and intelligent mine fuzes featuring full width attack capabilities has dramatically changed mine warfare. Unfortunately, not all mine training devices have kept pace with these developments. A distinction must be made at this point between those training mines classified as drill mines and those classified as practice mines. Drill mines are used to train engineer troops to correctly handle mines, while practice mines are used to train non-engineer combat troops about mine warfare. Drill mines therefore simply have to mimic the arming and disarming procedures of the newer types of mines; they do not have to offer all the features of these advanced mines to have some training value. The practice type of training mine, because of its different training role, must emulate all features of the newer mines. However, existing practice mines do not do this; they are, for the most part, unrealistic in form, activation mechanism, and result. Because of this, these devices have little training value, and consequently the troops who encounter them do not fully appreciate the problems associated with mine warfare.

To rectify this problem, the Directorate of Military Engineering Requirements (DMER) tasked the Ordnance Detection Group (ODG) of the Defence Research Establishment Suffield (DRES) with designing and developing a realistic training mine to be used by mechanized infantry troops. Detailed information on the original concepts for the design of the training mine are found in [1]. The resulting training mine, named the DRES Practice Mine, features:

1. a full width attack capability,
2. a visual indication of fuze initiation,
3. an appearance similiar to that of a real mine, and
4. little or no hazard to troops who encounter it.

To provide these features, the design of the Practice Mine incorporated three distinct electrical subsystems into a plastic olive drab case which was made to have the appearance of a real mine. These three subsystems are:

1. a sensing subsystem consisting of a seismometer, a magnetometer and signal conditioning circuitry,

2. a subsystem consisting of programmable digital electronic components, which provides the Practice Mine with the rudimentary intelligence needed to emulate a modern mine, and

3. a replaceable smoke charge.

The signals from the sensors change with the approach of a vehicle. The digital electronics quantify the change and determine when the vehicle is over the mine. At this point, the digital electronics command the firing of the smoke charge. This design gives the Practice Mine a full width attack capability and the ability to provide a visual indication of initiation.

Figure 1.1 shows a Practice Mine complete with smoke charge. Figure 1.2 shows a top view of a Practice Mine without a smoke charge. Both the On/Off and Safe/Arm switches, the pyrotechnic well and two of the four flip disc displays used to indicate the mine's status are visible in this figure. Figure 1.3 shows a bottom view of a Practice Mine. The other two flip disc displays and the sky blue patch indicating that the mine is a training device are shown in this figure. As all three figures show, the Practice Mine has a mine-like appearance.

Safety concerns were paramount during the design of the Practice Mine. Redundancy within the digital electronics was one way chosen to minimize the potential hazards of the Practice Mine. Within each unit are two microprocessors operating independently of each other. These processors constantly check for faults in each other as well as in the remainder of the mine. If a fault occurs, one or both of the processors should detect it and cause the mine to stop operating, rendering a potentially hazardous mine safe.

In addition to the redundancy in the electronics, the circuitry used to set off the smoke charge was designed in such a way that a single component failure is not sufficient for an accidental initiation of the smoke charge when power is first applied. As the potential for any injury caused by the Practice Mine is greatest when power is first applied, this design feature greatly reduces the overall hazard level associated with the Practice Mine as a whole. Finally, the only hazardous part of the mine, the smoke charge, was chosen on the basis that it does not pose a life-threatening hazard. These design features should ensure that the Practice Mine will pose little or no hazard to troops who encounter it.

Following completion of the design of the electronics, a contract with the Advanced Technology Center of Honeywell Canada was let to design the Practice Mine case and to produce 200 units complete with electronics to allow for testing by elements of the Canadian Forces. In addition, 1000 smoke marker units were

produced through a contract with Hands Fireworks for the same reason. At the date of writing of this document, the evaluation had not taken place.

The two microprocessors described earlier control the behaviour of the Practice Mine. As these devices are themselves controlled by the microcode resident within them, a knowledge of this controlling software is crucial to understanding the Practice Mine. A description of the software can be found in [2]. However, this report does not describe in any detail the hardware within the Practice Mine. To gain a complete understanding of the Practice Mine, the hardware details must also be known. These details are described in this report.

Figure 1.4 shows a block diagram of the electronics within the Practice Mine. A complete schematic can be found in Appendix C. Each element within the block diagram is discussed in this report. The battery arrangement used to power the mine is not explicitly shown in the figure but is discussed as a knowledge of the power supply is essential in order to fully understand the mine hardware.

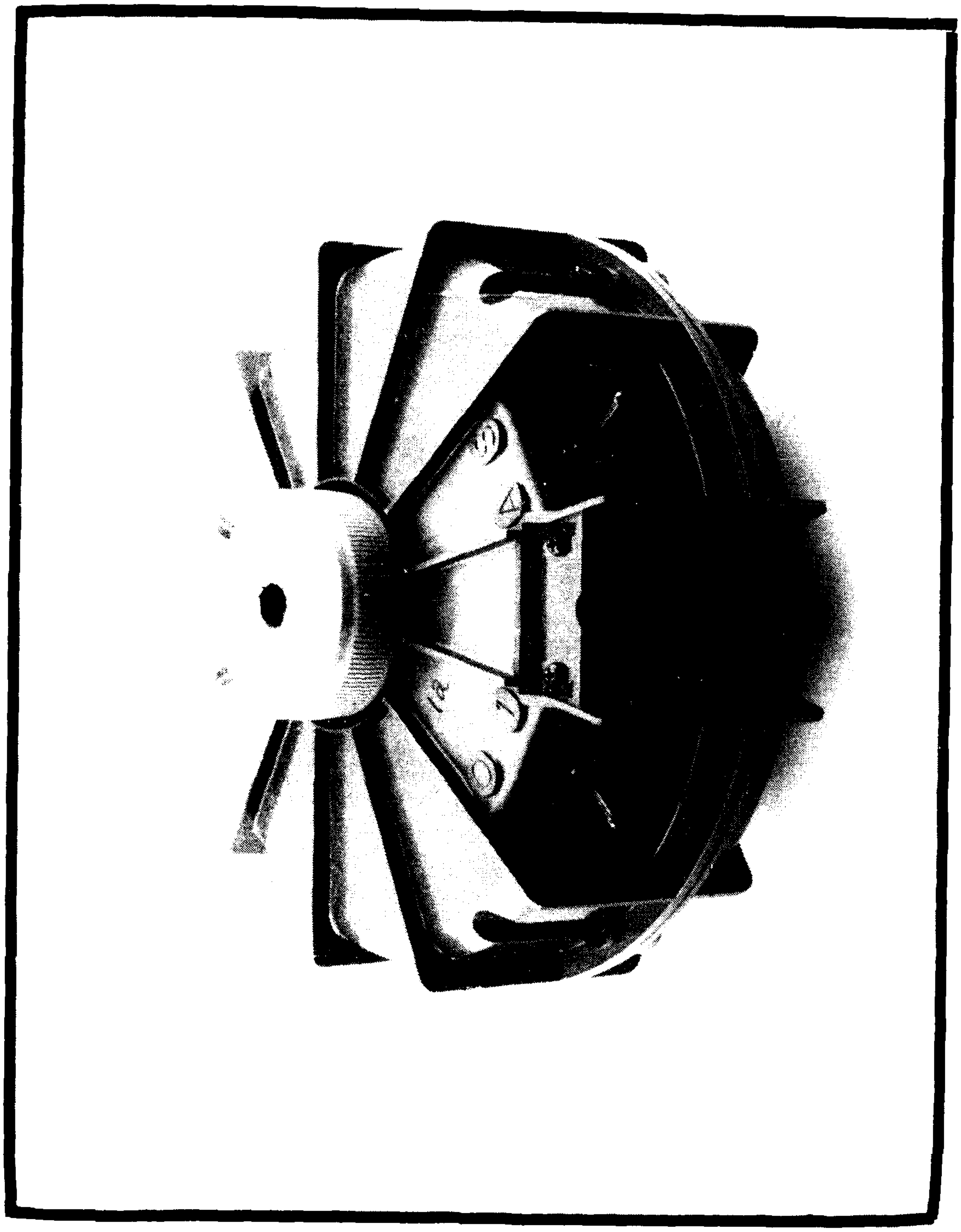

Figure 1.1

PHOTO OF PRACTICE MINE AND SMOKE CHARGE

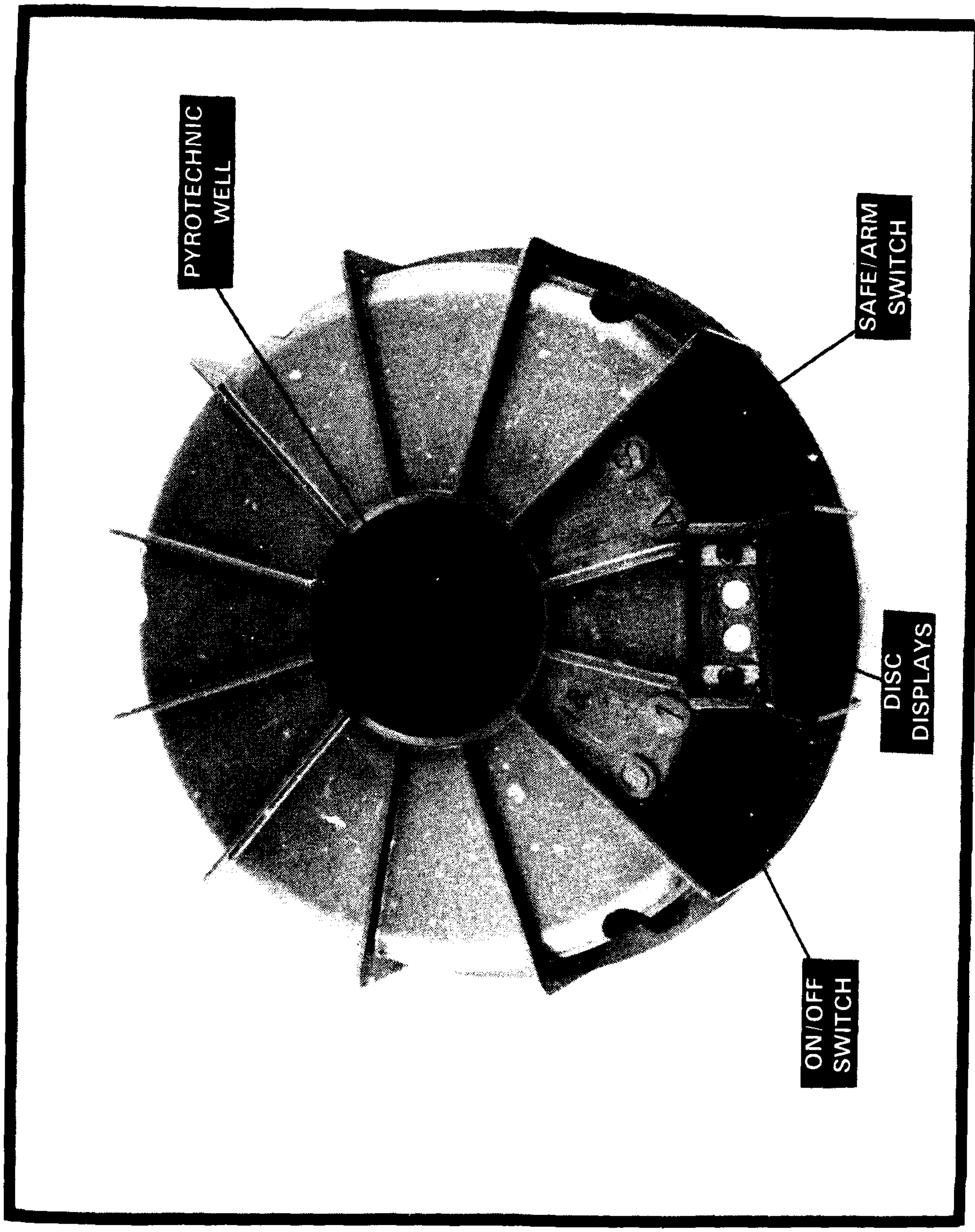

Figure 1.2
TOP VIEW OF PRACTICE MINE

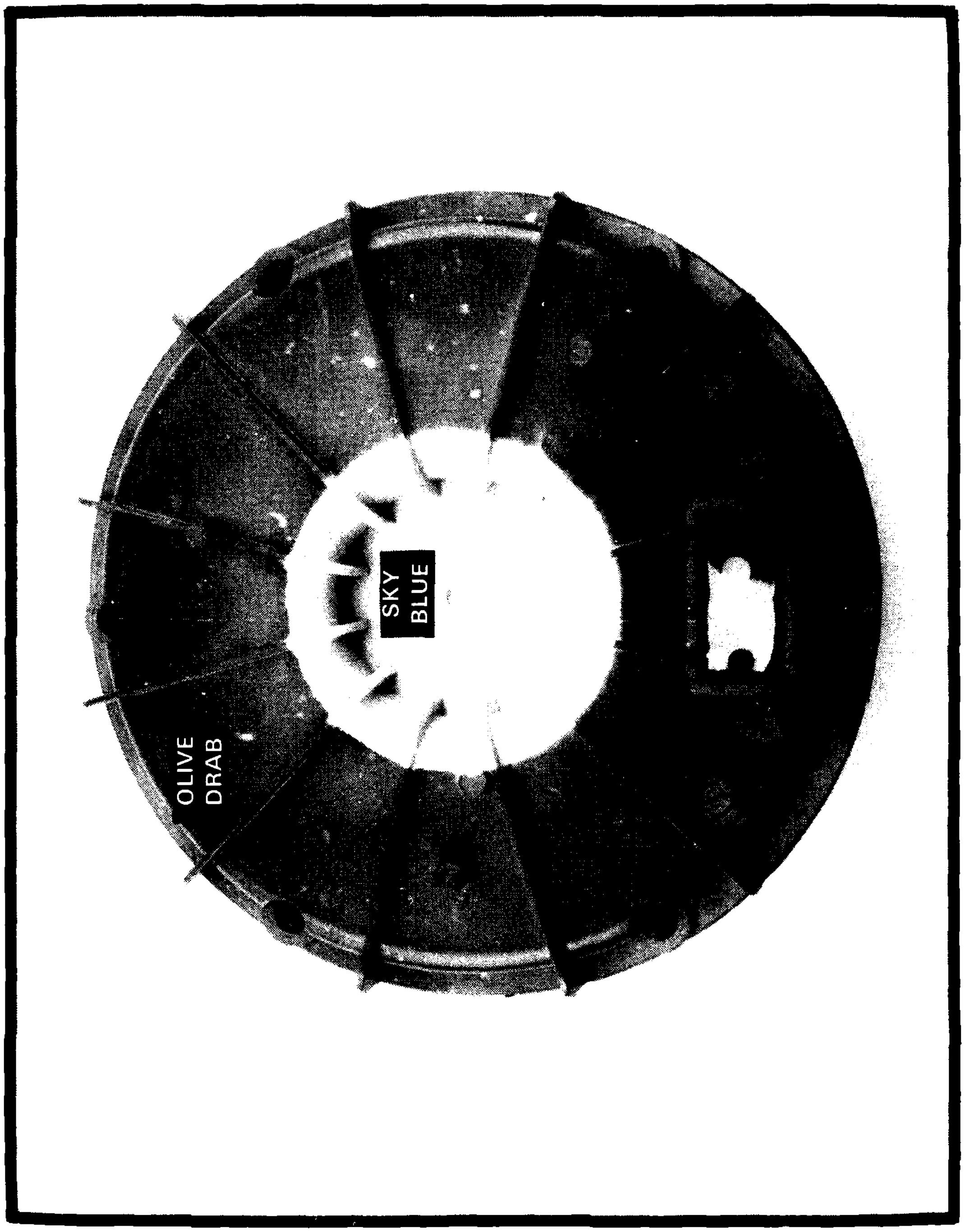

Figure 1.3
BOTTOM VIEW OF PRACTICE MINE

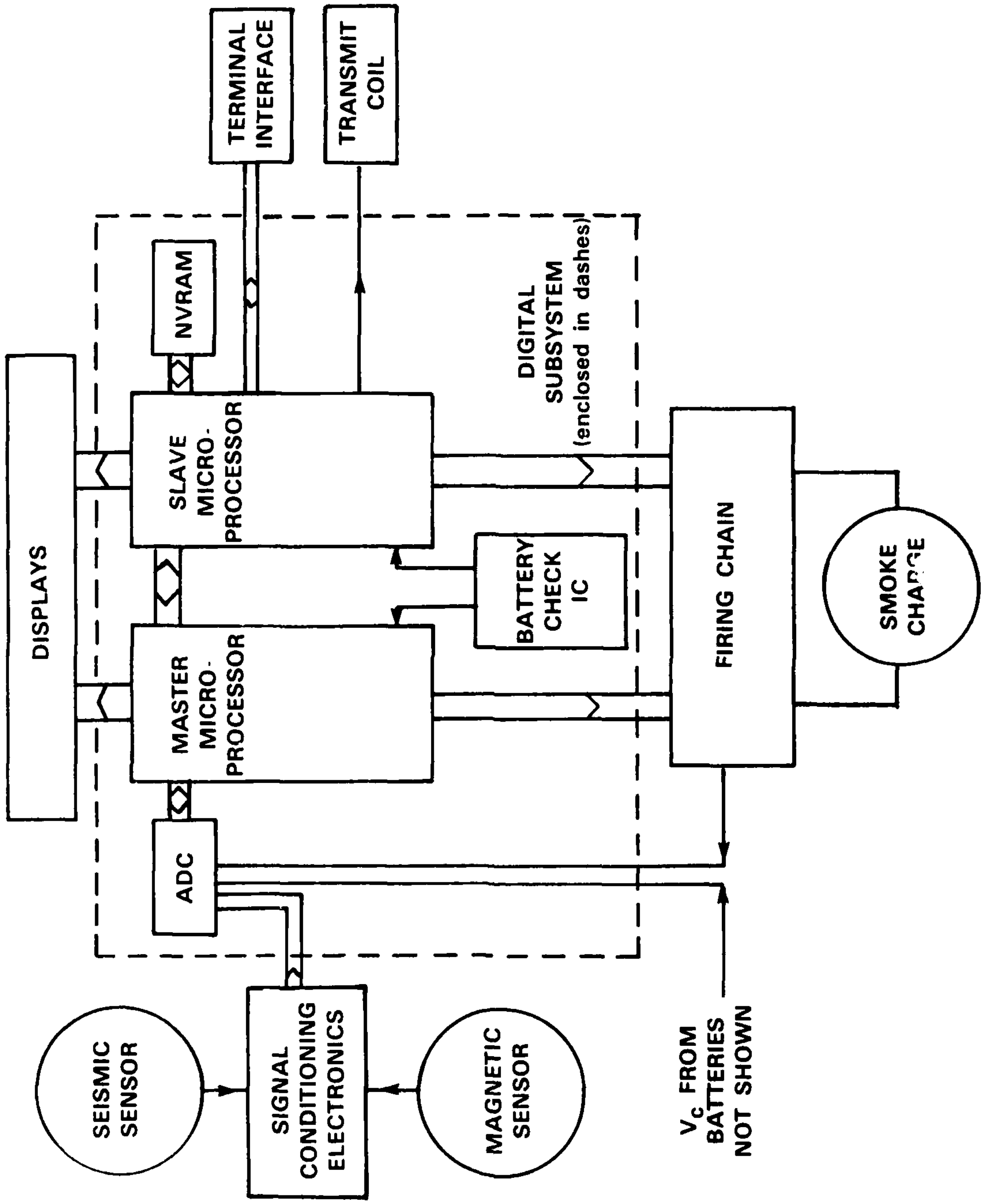

Figure 1.4

BLOCK DIAGRAM OF THE PRACTICE MINE ELECTRONICS

2. Power Supply

Power is supplied to the mine by six AA batteries. Figure 2.1 shows the configuration of the power supply buses. Battery groups B1, B2 and B3 consist of two AA cells, each with a terminal voltage of 1.5 volts when new. As such, the nominal voltage at nodes E and V_R is 6 volts while at node V_C it is 3 volts. The switch in the figure is the On/Off switch shown in the off position.

Battery groups B3 and B2 supply power through the E bus to both sensors, to the analog signal conditioning circuitry associated with these sensors, and through the V_{CC} bus to all the digital electronic devices within the mine, as well as to a portion of the firing chain circuitry. The V_{CC} bus is not separate from the E bus. In fact, it is fed by the E bus and its voltage is simply a diode drop, 0.7 volts, below the E bus voltage. This feature was incorporated into the mine in order to ensure that the absolute maximum voltage rating of the microprocessors could not be exceeded at any time during the operating life of the mine. This absolute maximum value is 5.5 volts. Supplying the microprocessors with power directly from the E bus would have meant that the absolute maximum would be exceeded by 0.5 volts until the terminal voltage of each of the four cells within B2 and B3 had fallen to approximately 1.37 volts. In order to avoid this, and any resulting damage to the processors that could be caused by operating above the maximum, the diode was introduced into the E bus and all digital devices became powered from the resulting V_{CC} bus.

Battery groups B3 and B1 supply power through the V_R bus to the transmit coil, the flip disc displays and to the smoke charge within the firing chain circuitry. The smoke charge and displays sink a large quantity of current when energized. The amount required is typically hundreds of milliamps compared to less than 20 milliamps required by the electronics. This large current draw is not required constantly; it is needed only when the devices are energized. When these devices are energized however, the large current draw has the unfortunate effect of rapidly dropping the terminal voltage of the batteries supplying the current. If the E bus had been required to supply power to both the electronics and these current hungry devices, then the drop could have caused the electronics to malfunction.

In an attempt to isolate the electronics from any undesirable consequences of the rapid drop in supply voltage, battery group B1 was incorporated into the power supply. Note that this does not afford total isolation of the electronics from the devices requiring the large current draw as they are still related through battery group B3. Any large current draw in bus V_R that drops the voltage at V_C will also drop the voltage in the E bus by a corresponding amount. However, the rationale behind the incorporation of B1 maintained that this group would provide the extra capacity needed to supply any large current draw, while battery group B2 would hold the E bus above the minimum voltage necessary for the electronics to continue to function correctly should V_C drop. In this way, any unfortunate consequences of the voltage drop on the electronics could be avoided, while at the same time the costs of a fourth set of two AA cells, which would be necessary for total isolation, could also be avoided.

The circuitry for the transmit coil was designed in such a way that the current through it would be limited to less than 1.5 mA. As such, it could be powered by the E bus without causing any problems to the E bus voltage. However, the incorporation of B1 into the design of the power supply had already occurred; the decision was made therefore to take advantage of the extra capacity of the V_R bus by using it to supply power to the coil.

Figure 2.1 shows the smoke charge connected across supply nodes V_R and V_C. This was incorporated into the mine design for two reasons. First, the safety features designed into the firing chain demanded implementation in this way (see chapter 7). Second, this implementation ensured that the current drawn by the smoke charge upon ignition would not affect the voltage at bus E, as the current passes through B1 only. As a result, there is no opportunity for the microprocessors to malfunction due to supply voltage problems at the crucial time of smoke charge ignition.

Besides being used as a pseudo-ground for the smoke charge, voltage bus V_C is also used to provide a reference voltage that the digital electronics monitor as a check of the health of the analog to digital converter (ADC). The value of V_C is determined by the ADC periodically. The resulting value should be just slightly more than exactly half of the maximum value possible, as V_C is just slightly more than half the value of the V_{CC} bus, which supplies the full range reference voltage for the ADC.

To change the batteries, the mine case must be opened. This is an undesirable feature as six bolts must be loosened and dirt and other foreign material may enter the case and contaminate the electronics. Figure 2.2 shows an opened mine. The batteries are held in plastic holders which have a tendency to crack and break when the mine is handled roughly. Also, the only devices ensuring that the batteries stay in their holders during rough handling are the three foam

battery pads which, over time, lose their ability to keep the batteries in their holders. In either case, rough handling may render the mine inoperative due to failure of the batteries to remain in place.

Appendix A furnishes information on the power consumption of the mine.

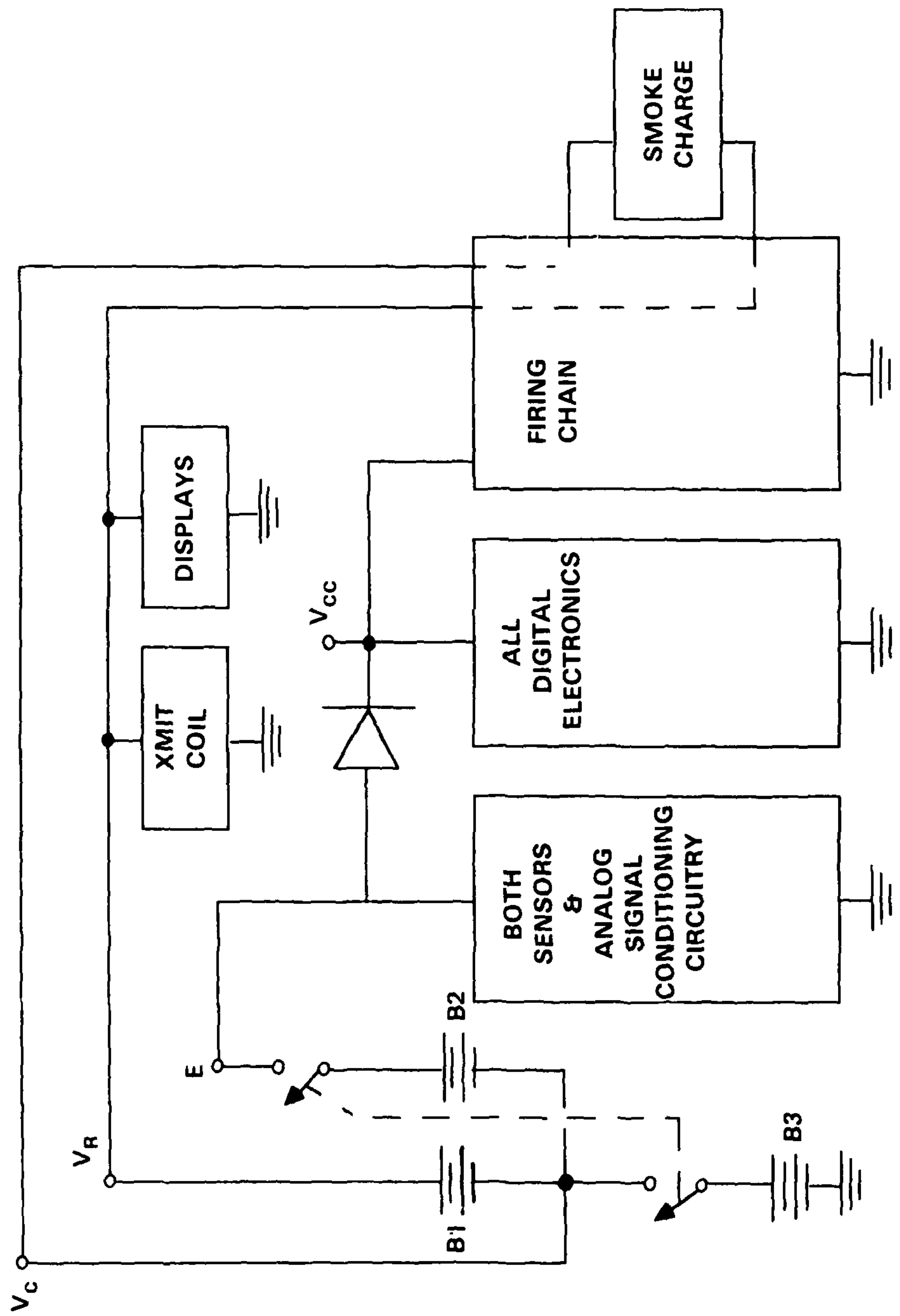

Figure 2.1
SUPPLY BUS CONFIGURATION

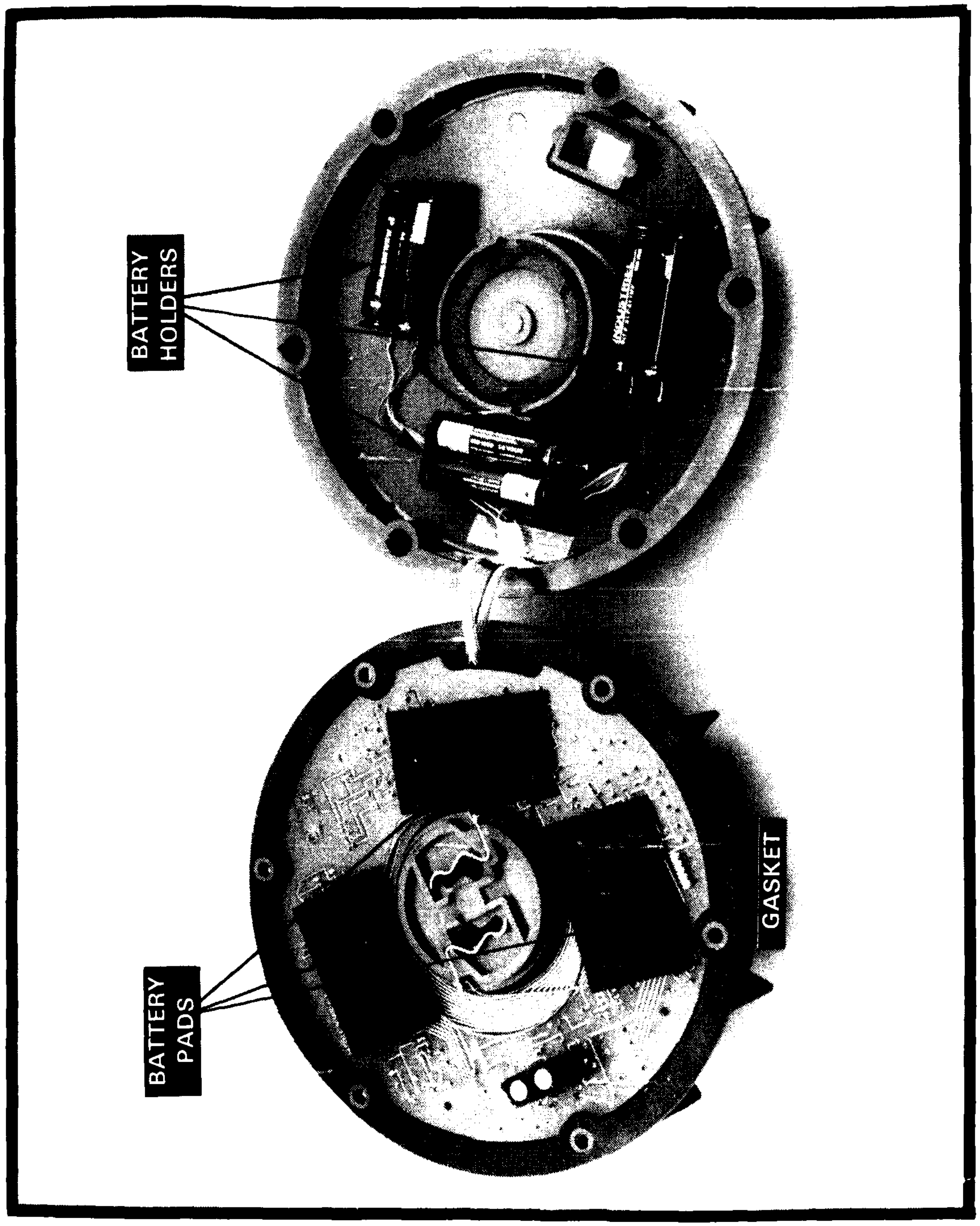

Figure 2.2
OPEN MINE SHOWING BATTERIES

3. Digital Electronics

In the block diagram of the Practice Mine electronics shown in figure 1.4, the digital electronic subsystem is shown enclosed in dashes. This subsystem consists of:

1. the Master and Slave microprocessors,
2. the analog to digital converter (ADC),
3. the battery check IC, and
4. the non-volatile memory (NVRAM).

The most important components of this subsystem are the two microprocessors.

3.1 Microprocessors

The two microprocessors are responsible for the overall functionality of the Practice Mine. To accomplish this, both processors must:

1. directly control the displays and the smoke charge firing chain,
2. determine, through the use of the battery check IC, when the batteries have become exhausted,
3. check for problems within each other.

In addition to those duties which both processors perform, each processor performs a number of functions by itself. The Master determines the presence of vehicles or faults within the mine through the use of the ADC. The Slave meanwhile:

1. communicates with external users through the terminal interface and the transmit coil,

2. updates the fuze and self-neutalization parameters within the NVRAM, and,

3. determines the position of the Safe/Arm switch.

The Master and Slave designations used for the two processors were not chosen to imply that one processor is somehow subservient to the other. Instead, the processor designated as the Master contains the fuze algorithm while the one designated as the Slave does not.

The same type of microprocessor is used for both Master and Slave units. This is the Motorola MC1468705G2. This 40 pin CMOS IC is a user programmable, single chip version of the MC6805. Each chip contains 2106 bytes of EPROM (Erasable Programmable Read Only Memory) used to store the microcode programs that control both Master and Slave processors, as well as 112 bytes of RAM (volatile Random Access Memory) used for the storage of variables. A ROM variant of this IC is available should the Practice Mine go into large scale production.

To communicate with and control the other devices within the mine, each microprocessor contains four 8 bit bidirectional I/O (input/output) ports. Each of these 32 I/O lines can be individually configured to send or receive a digital signal. This signal may, for example, turn on a transistor which in turn energizes the locator coil and sends the locate tone (see section 5.2), or it may indicate that the V_{CC} battery voltage has fallen below 4 volts (see section 3.3). These signals will be described in further detail throughout the remainder of this report.

Twelve of the I/O lines connect the two processors together. Table 3.1 shows the lines involved in this interprocessor connection. Six of the lines, each beginning with ST in table 3.1, are used to send the current state of the two processors to each other. Each processor controls three of these six lines and periodically checks the remaining three to determine the state of the other processor. Tables 3.2 and 3.3 describe the various states of the two processors.

The other six lines used to connect the two processors together provide serial communication links between the two units. The Master transmits information to the Slave through the use of signals DTXM, DVM and ACKS. The actual information is sent, one bit at a time, on DTXM. Each time a new bit is sent, the Master asserts DVM to indicate to the Slave that valid data is being sent. The Slave reads line DTXM and acknowledges receipt of the information by asserting ACKS. The Master then sends the next bit. The Slave transmits information to the Master in a similar fashion. However, its uses line DTXS in place of DTXM and asserts DVS whenever valid data is being sent. The Master acknowledges receipt of the information by asserting ACKM.

Pin 29 or I/O line 0 within port D is used to determine if the processor has been inserted into the wrong socket on the PC (printed circuit) board. When the mine is first turned on, both processors check the state of this line. The PC board was designed so that this line is connected to V_{CC} on the Master, while it is grounded on the Slave. If the processor senses the wrong level at this pin, it goes into an error state and ceases operation. In addition, this line could be used to indicate to the processor which program to execute if both Master and Slave code could be amalgamated into one IC. Currently, the size of the EPROM is too small to accommodate both programs.

The MC1468705G2 microprocessor used in the 200 pre-production units has an operating temperature range of 0° to 70°C. Additional information on the MC1468705G2 can be found in the manufacturer's data book [3].

3.2 A to D Converter

A vehicle approaching a Practice Mine will create seismic and magnetic disturbances which are detected by the seismometer and magnetometer within the mine. These disturbances will appear as fluctuating voltage levels at the output of the sensors. In order for these fluctuations to be correctly interpreted by the mine, they must be quantified into values which the electronics can understand. An analog to digital converter (ADC) connected to the Master is used for this purpose.

The ADC presently used within the Practice Mine is a National Semiconductor ADC0844. This device uses successive approximation to convert one of four possible analog input voltages to an eight bit digital output value. The output values range from 00 when the input is grounded, to 255 when the full range voltage is present. The reference voltage applied to the ADC is V_{CC}; this is also the full range voltage. The reference voltage is supplied by the same bus that supplies power to the ADC as well as to the rest of the digital electronics within the mine. An analog ground, as well as a digital one, must be applied to the ADC. These two are the same in the Practice Mine. The chip is fabricated using CMOS technology, ensuring low power consumption. The variant used in the 200 pre-production mines has an operating temperature range of 0° to 70°C.

The ADC has a four to one multiplexer at its analog input. This allows the ADC to digitize up to four different analog signals, although not simultaneously. The four signals converted by the ADC within the Practice Mine are:

1. the output of the seismometer,
2. the output of the magnetometer,

3. the voltage at one of the smoke charge squib terminals, V_{SQ}, (see chapter 7)

4. bus voltage V_C, (see chapter 2)

The Master selects which of the four possible inputs signals are to be converted by the ADC by specifying a channel or input address to the ADC. Each input signal has a unique channel address associated with it.

Figure 3.1 shows the connections between the Master microprocessor and the ADC. Converted values are sent by the ADC to the Master over lines DB0 to DB7. The least significant bit of this 8 bit value is DB0. Multiplexed with lines DB0 to DB3 are the lines MA0 to MA3. The Master sends the channel address of the analog signal to be digitized to the ADC on these four lines. Lines DB7 to DB0 connect to I/O lines 7 to 0 within port A. These 8 lines correspond to pins 4 to 11 on the Master.

Control signals are communicated between the Master processor and the ADC on the lines $\overline{WR}$, $\overline{INTR}$, $\overline{RD}$ and $\overline{CS}$. Of the four, only $\overline{INTR}$ is sent by the 0844 to the Master; the remainder are all sent to the 0844 by the Master. The ADC asserts $\overline{INTR}$ to indicate that the present conversion cycle is completed. The Master sends various signal combinations on lines $\overline{WR}$, $\overline{RD}$ and $\overline{CS}$ to the ADC. These combinations command the ADC to:

1. latch the desired channel address into the multiplexer,

2. initiate a conversion cycle, or,

3. latch the converted data to the outputs of the ADC.

Lines $\overline{CS}$, $\overline{WR}$, $\overline{RD}$ and $\overline{INTR}$ connect to I/O lines 0 to 3 within port B. These four lines correspond to pins 12 to 15 on the Master.

The operating voltage range of the ADC0844 is 4.5 to 6.0 volts. However, the mine operates until the voltage on the bus supplying power to the digital electronics, V_{CC}, falls to 4.0 volts (see section 3.3 and Appendix A). In order to determine if operating below 4.5 volts would cause problems with the ADC, an experiment was conducted. The voltage supplying the ADC was decreased, and the values converted by the ADC were examined. No problems manifested themselves until the voltage reached 3.0 volts.

Additional information about the ADC0844 can be found in the manufacturer's literature [4].

3.3 Battery Check

The mine will operate until the voltage of the bus supplying the digital electronics with power falls below 4 volts. At this time, the unit will enter into a

failure condition. The Intersil ICL8211 integrated circuit is responsible for signaling to the microprocessors that this bus voltage has fallen to the 4 volt level. The 8211 is intended for use in applications requiring precise voltage detection. The variant chosen for use in the 200 pre-production units has an operating temperature range of 0° to 70°C.

The 8211 is a bipolar device, not a CMOS one like most of the remainder of the integrated circuits within the mine. However, even though it is fabricated from the more power-hungry technology, it draws less current than the CMOS devices, as table A.5 shows. As such, it is suitable for use within the Practice Mine.

The 8211 has different modes of operation. The simplest mode is used within the mine. The output of the device will be high or a "1" until the voltage at its THRESHOLD input falls below 1.15 volts. At this time, the output of the 8211 will go low to the "0" state. A resistor divider network connected between the THRESHOLD input and the V_{CC} bus ensures that the 8211 trip voltage is reached when the bus voltage falls to 4 volts. The output is connected to pin 30, or I/O line 1 within port D, on both the Master and Slave microprocessors. As a result, the two processors can determine when the 4 volt level has been reached by periodically checking the level at this pin.

Figure 3.2 shows the connection between the 8211, the processors and the V_{CC} bus. Resistors R_{32} and R_{31} form the divider network. R_8 is a pull-down resistor. Additional information on the ICL8211 can be found in the manufacturer's databook [5].

3.4 Non-Volatile Memory

Both the self-neutralization time and the fuze parameters within a Practice Mine can be changed without having to reprogram both microprocessors. Instead, these two quantities are updated by changing the contents of a non-volatile memory IC connected to the Slave processor. This is done through the use of a computer terminal which communicates with the Slave processor when connected to the mine (see section 5.1). New values are sent via the terminal to the Slave, which transfers them to the non-volatile memory IC or NVRAM (Non-Volatile Random Access Memory). Immediately after a mine is turned on, its Slave processor reads the contents of the NVRAM and transfers the necessary parameters to the Master processor.

The NVRAM used in the Practice Mine is the Xicor X2444. This is a 256 bit serial non-volatile static RAM. The device is organized as 16 words with 16 bits per word. The self-neutralization time and fuze parameters consist of multiple

strings of 8 bit bytes. As a result, each word within the NVRAM comprises two bytes of parameter information. The memory portion within the NVRAM consists of a static RAM and an E^2PROM (Electrically Erasable Programmable Read Only Memory). Every bit within the RAM is mapped to a corresponding bit within the E^2PROM. Data to be stored within the NVRAM is first written to the static RAM, then the RAM contents are used to overwrite the E^2PROM. Similarly, when the data is retrieved from the device, the E^2PROM information overwrites the RAM contents, then these new RAM contents are tranferred to the Slave.

Data is transferred serially between the Slave and the NVRAM on three lines. The DI line carries data from the Slave to the NVRAM. Data is transferred from the NVRAM to the Slave on the DO line. The SK line, controlled by the Slave, clocks the two data lines. The data sent to the NVRAM from the Slave can consist of a code indicating a storage or retrieval operation, an address for data storage or retrieval, the actual information to be stored, or a combination of the three. The data sent to the Slave from the NVRAM consists solely of the information stored previously within the device. A fourth line connecting the Slave and the NVRAM is a CE or chip enable signal, which the Slave uses to alert the NVRAM to the possibility of action between the two devices. Figure 3.3 shows the connections between the two devices. The CE line on the NVRAM is connected to pin 5 on the Slave, which corresponds to line 6 within I/O port A. Lines DO, DI and SK connect to pins 8, 9 and 10 on the Slave, which correspond to lines 3, 2 and 1 respectively within I/O port A.

The NVRAM interacts with the Slave only when the stored parameters are recalled for use within the mine, or when the old parameters are replaced with new ones. For most of the operating life of the mine, the NVRAM does nothing. In order to minimize the power consumed by this device, transistor Q15 was incorporated into the circuit supplying power to the NVRAM, as shown in figure 3.3. When Slave pin 11 (I/O line 0 within port A) is low, transistor Q15 will conduct and supply power to the device. After the Slave has finished interacting with the NVRAM, it can disconnect the device from the supply bus by bringing pin 11 high. In this way, the power drain caused by the NVRAM is greatly minimized.

The NVRAM variant used in the 200 pre-production units has an operating temperature range of 0° to 70°C. Additional information about the NVRAM can be found in the manufacturer's literature [6].

Master			Signal	Slave		
Pin	I/O line	I or O	Name	Pin	I/O line	I or O
16	port B line 4	O	ST0M	24	port C line 4	I
17	PB5	O	ST1M	23	PC5	I
18	PB6	I	ST0S	22	PC6	O
19	PB7	I	ST1S	21	PC7	O
21	PC7	I	ST2S	19	PB7	O
22	PC6	O	ST2M	18	PB6	I
23	PC5	I	ACKS	17	PB5	O
24	PC4	O	DVM	16	PB4	I
25	PC3	O	DTXM	15	PB3	I
26	PC2	O	ACKM	14	PB2	I
27	PC1	I	DVS	13	PB1	O
28	PC0	I	DTXS	12	PB0	O

Table 3.1: Master–Slave Interconnections

Signal			State Description
ST2M	ST1M	ST0M	
0	0	0	Disarmed – waiting to be armed
0	0	1	Test mode
0	1	0	Count to arm
0	1	1	Armed
1	0	0	Fire command to Slave
1	0	1	V_{SQ}^{*}, ADC, battery or RAM failure
1	1	0	Slave or procedure failure
1	1	1	Disarmed after firing or time elapsed

* squib voltage, see chapter 7

Table 3.2: Master Processor State Description

Signal			State Description
ST2M	ST1M	ST0M	
0	0	0	Disarmed – waiting to be armed
0	0	1	Test mode
0	1	0	Count to arm
0	1	1	Armed
1	0	0	Fire squib
1	0	1	NVRAM, battery or onboard RAM failure
1	1	0	Master or procedure failure
1	1	1	Disarmed after firing or time elapsed

Table 3.3: Slave Processor State Description

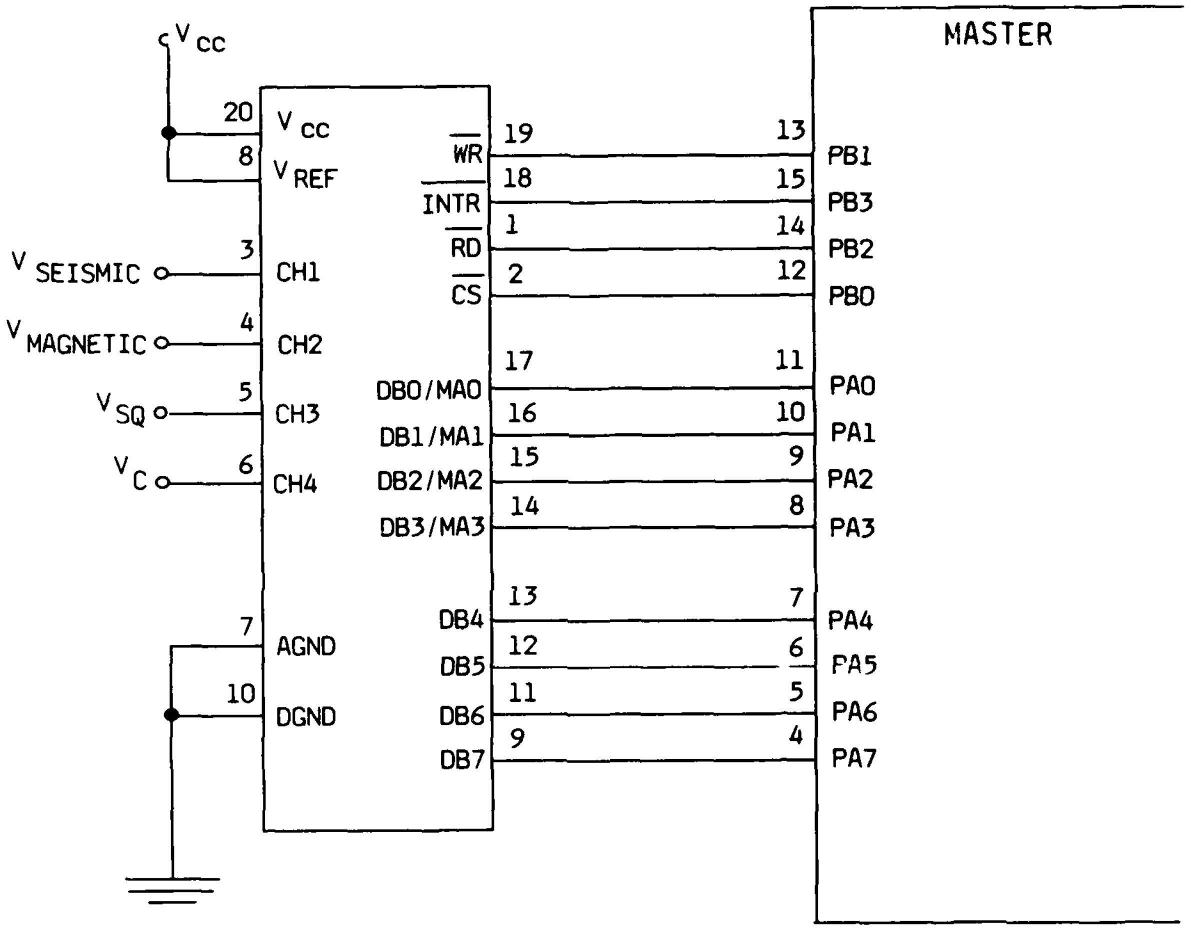

Figure 3.1

ADC INTERCONNECTIONS

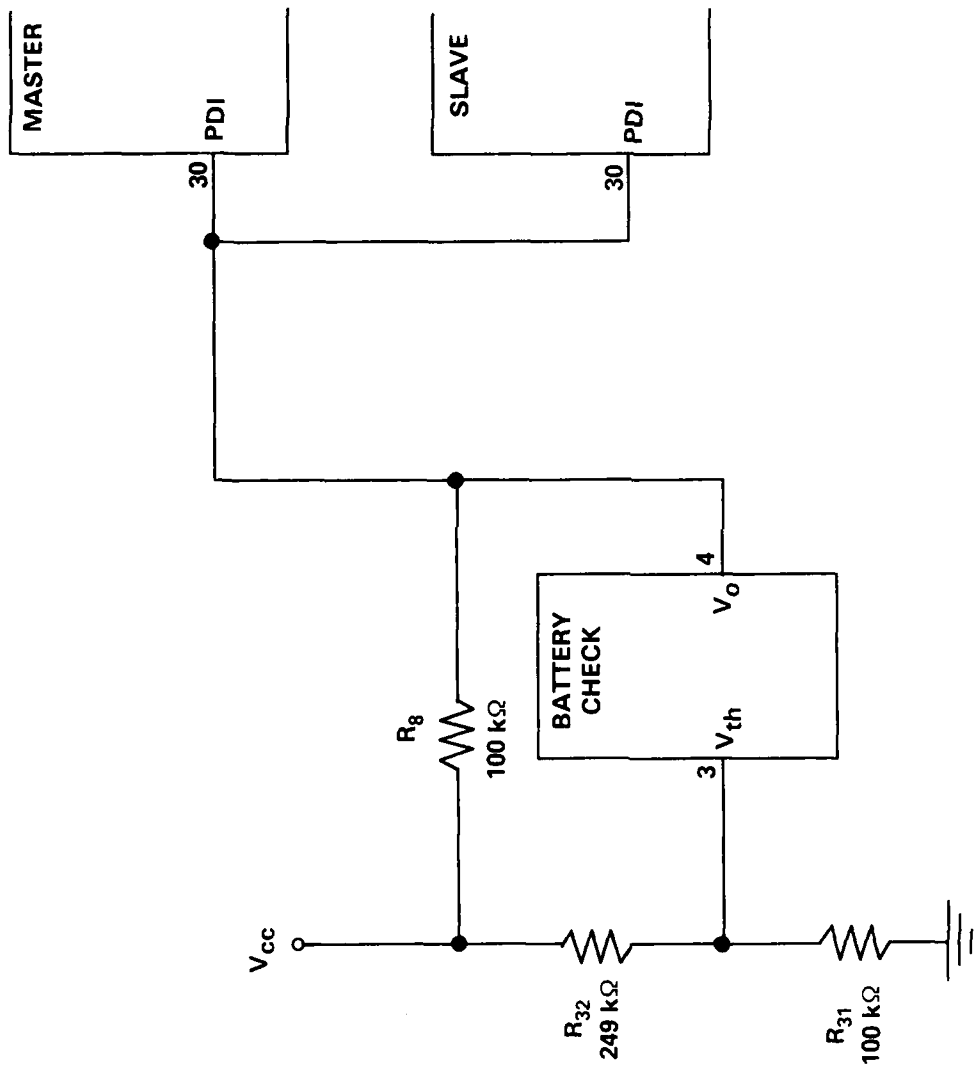

Figure 3.2

BATTERY CHECK IC INTERCONNECTIONS

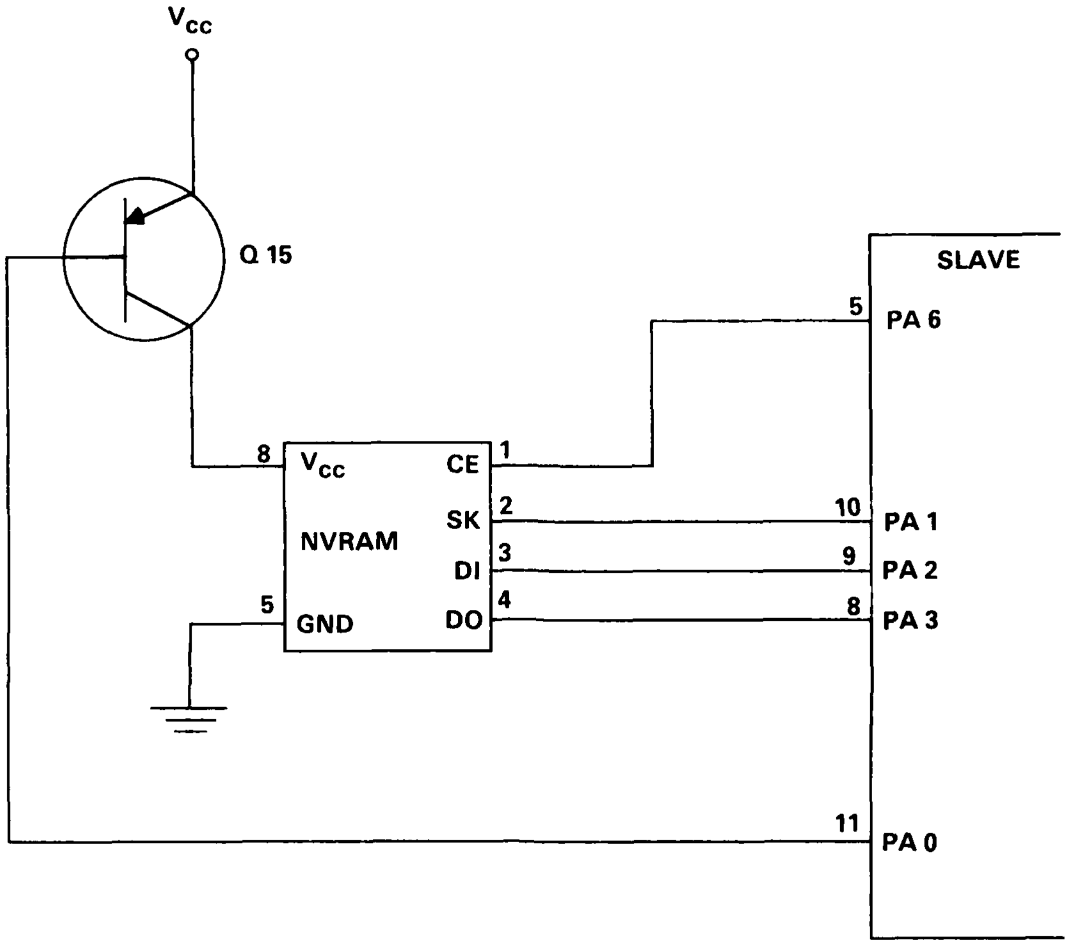

Figure 3.3

NVRAM INTERCONNECTIONS

4. Analog Electronics

The analog electronics within the Practice Mine consist of:

1. a low-power Brown magnetometer,
2. a ceramic vibration sensor used as a seismometer, and
3. signal conditioning electronics, consisting of various operational amplifiers configured as band-pass filters.

4.1 Magnetometer

The magnetometer used within the Practice Mine is a flux-gate device originally designed by Brown [7]. This design was chosen because of its low power consumption, inherent stability, compactness and because the design was proven in many other applications.

The magnetometer was fabricated from discrete components by Valcom Ltd. under a contract to manufacture the devices according to design specifications provided by DRES. The components are soldered to a 4.5 cm long by 3.5 cm high PC board. This board in turn is soldered to the main mine PC board. In the resulting assembly, the magnetometer board is perpendicular to the main PC board. Figure 4.1 shows the location of the magnetometer with respect to the main PC board.

The magnetometer is a four terminal device. Power and ground are supplied on two of these four terminals, while the remaining two provide the output of the magnetometer in a differential mode. Power to the device is supplied by the E bus. The magnetometer has a sensitivity of approximately 2 volts per 100,000 nT.

4.2 Seismometer

The seismometer used within the Practice Mine is a subminiature ceramic vibration transducer manufactured by the Knowles Electronics Company [8].

The device is very small; its dimensions are 7 mm by 5 mm by 4 mm. Figure 4.1 shows the location of the seismometer. The unit is glued to the PC board and connected electrically by stiff wire "fingers" soldered between the device terminals and the corresponding traces on the board.

The seismometer has three terminals, but it can be connected in either a two or three terminal configuration. The three terminal configuration is used in the Practice Mine as a gain in sensitivity of approximately 10 dB can be realized when the device is connected in this way. Power and ground are supplied on two of the three terminals with the output signal present on the third. The E bus supplies power to the seismometer.

4.3 Signal Conditioning Circuitry

The signals from both sensors are conditioned by additional analog circuitry prior to conversion to digital values by the ADC. This additional circuitry performs a number of functions. Figure 4.2 is a schematic diagram of the magnetic channel signal conditioning circuitry. The first op-amp stage simply combines the differential signals leaving the magnetometer. The second op-amp stage both filters and amplifies the combined signal. The band-pass filter implemented in the second stage has 3 dB frequencies of approximately 0.2 and 23 Hz. The maximum possible gain of the filter is 5. Note that the sensor output is ac coupled by capacitor C_7. The dc level at the output of the filter is set by resistors R_{37} and R_{38} to be approximately half of V_{CC}.

Figure 4.2 shows that capacitors C_7 and C_8, and resistors R_{39} and R_{40} have two values associated with them, one of which is in brackets. Initially, the circuitry was designed and constructed using the bracketed component values. However, these values could not provide the desired filter response and their incorporation into the Practice Mine decreased the performance of the unit. This problem was corrected by replacing the bracketed component values with the non-bracketed ones. Table 4.1 shows the desired, initial and final filter parameters and resulting 3 dB points for the magnetic channel circuitry.

Figure 4.3 is the schematic diagram of the seismic channel signal conditioning circuitry. The first op-amp stage is a high-pass filter with a 3 dB frequency of approximately 0.7 Hz. The second op-amp stage is a low pass filter with a 3 dB frequency of about 72 Hz. The resulting band-pass filter has a maximum possible gain of 400. Capacitor C_{10} ac couples the seismometer output and thereby allows resistors R_{42} and R_{46} to set the dc bias of the output signal to approximately one third of V_{CC}.

Capacitors C_{10} and C_{11} have two values associated with them, for the same

reason as capacitors C_7 and C_8 and resistors R_{39} and R_{40} in the magnetic channel. Table 4.2 shows the desired, initial and final filter parameters and resulting 3 dB points for the seismic channel circuitry. In addition to the changes necessary to capacitors C_{10} and C_{11}, C_D was added to all 200 units following construction. This component was necessary to decouple the seismic signal from a spurious signal caused by the ADC and entering the seismic channel through the dc bias network. This spurious signal had a sawtooth shape with an amplitude of about 560 mV and a frequency equal to the digitization rate of 200 Hz. Once capacitor C_D was added, the amplitude dropped to 35 mV.

The LM2902 quad operational amplifier IC manufactured by National Semiconductor provides the four op-amps used within the two signal channels. The LM2902 is powered by the E bus. However, the positive rail of the device is limited to 1.5 volts below the positive voltage supply of the device. Consequently, both the seismic and magnetic signals cannot exceed a voltage equal to (E-1.5). With fresh batteries then, the maximum possible signal voltage would be 4.5 volts. The LM2902 variant used in the Practice Mine has an operating temperature range of -40° to +85°C. Additional information on the LM2902 can be found in the manufacturer's literature [9].

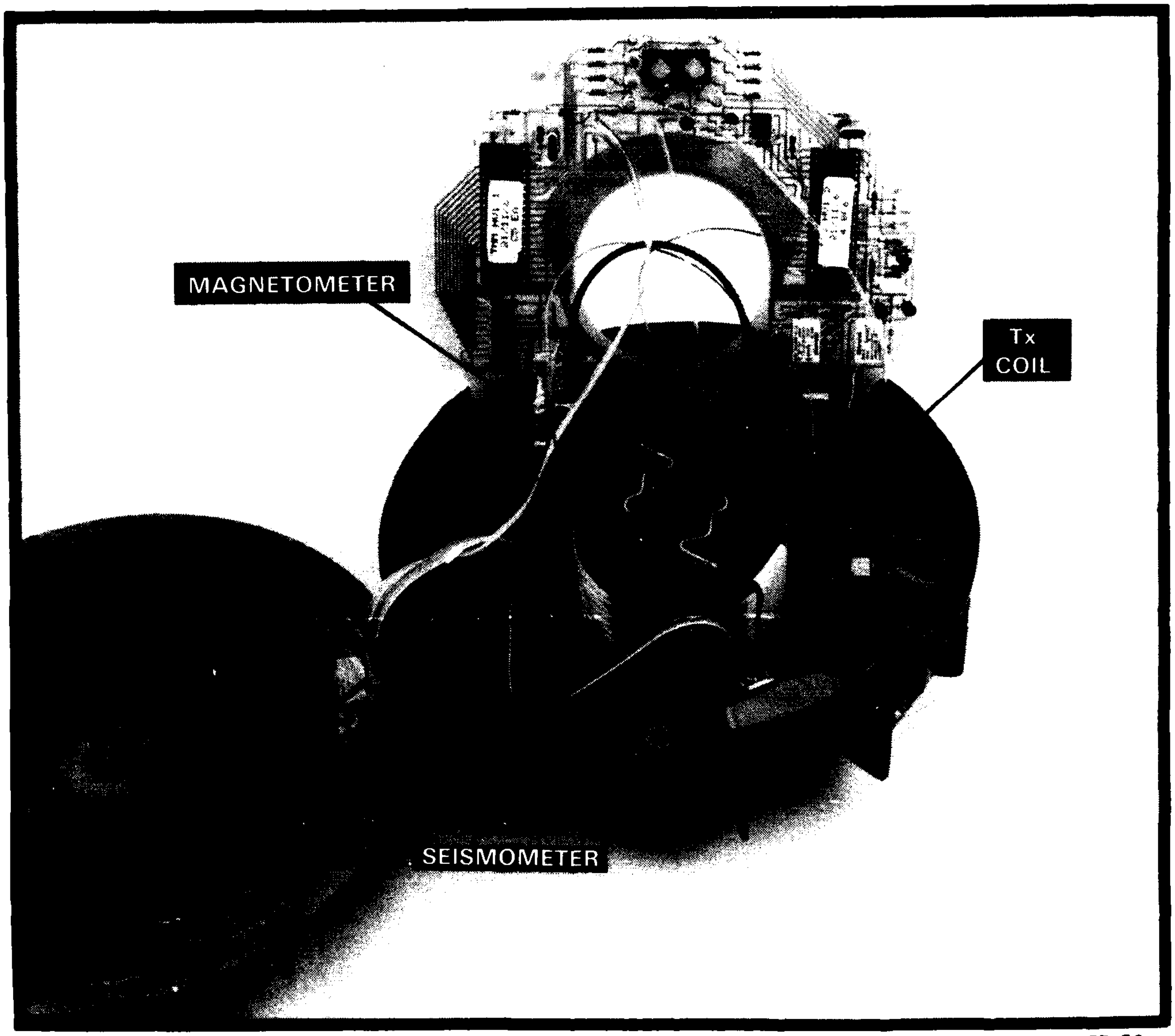

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Figure 4.1a

LOCATION OF SENSORS

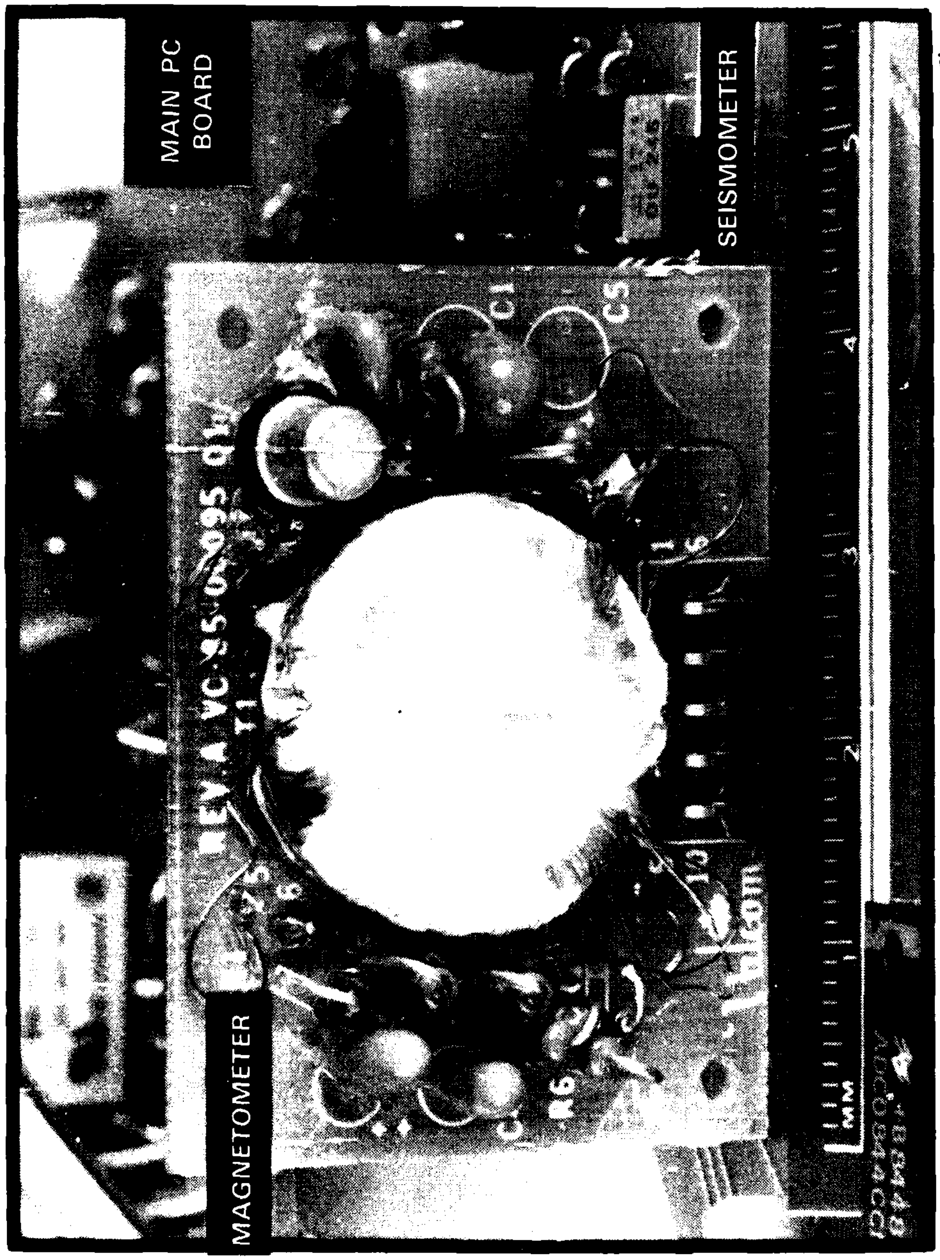

Figure 4.1b
LOCATION OF SENSORS

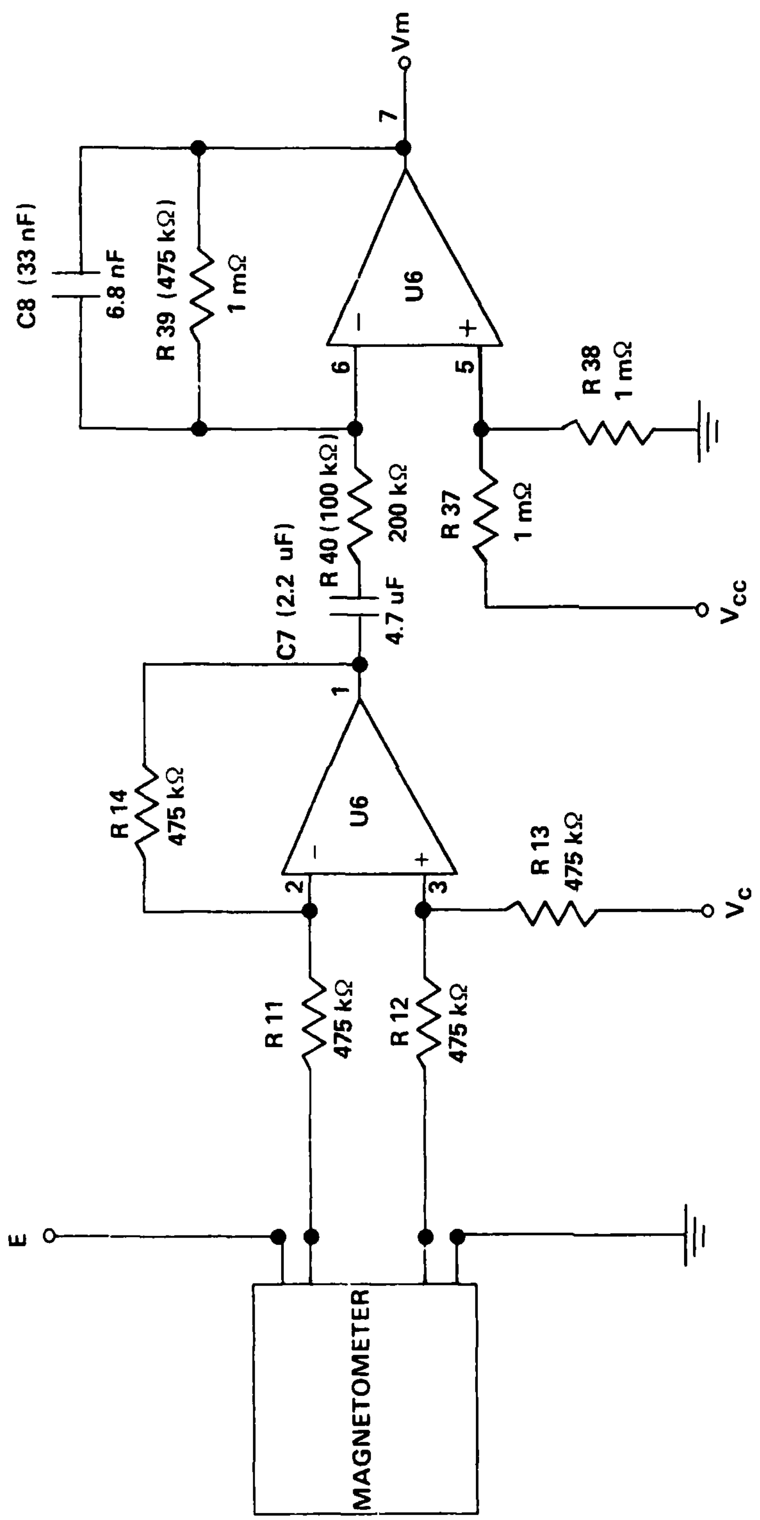

Figure 4.2
MAGNETIC CHANNEL ELECTRONICS

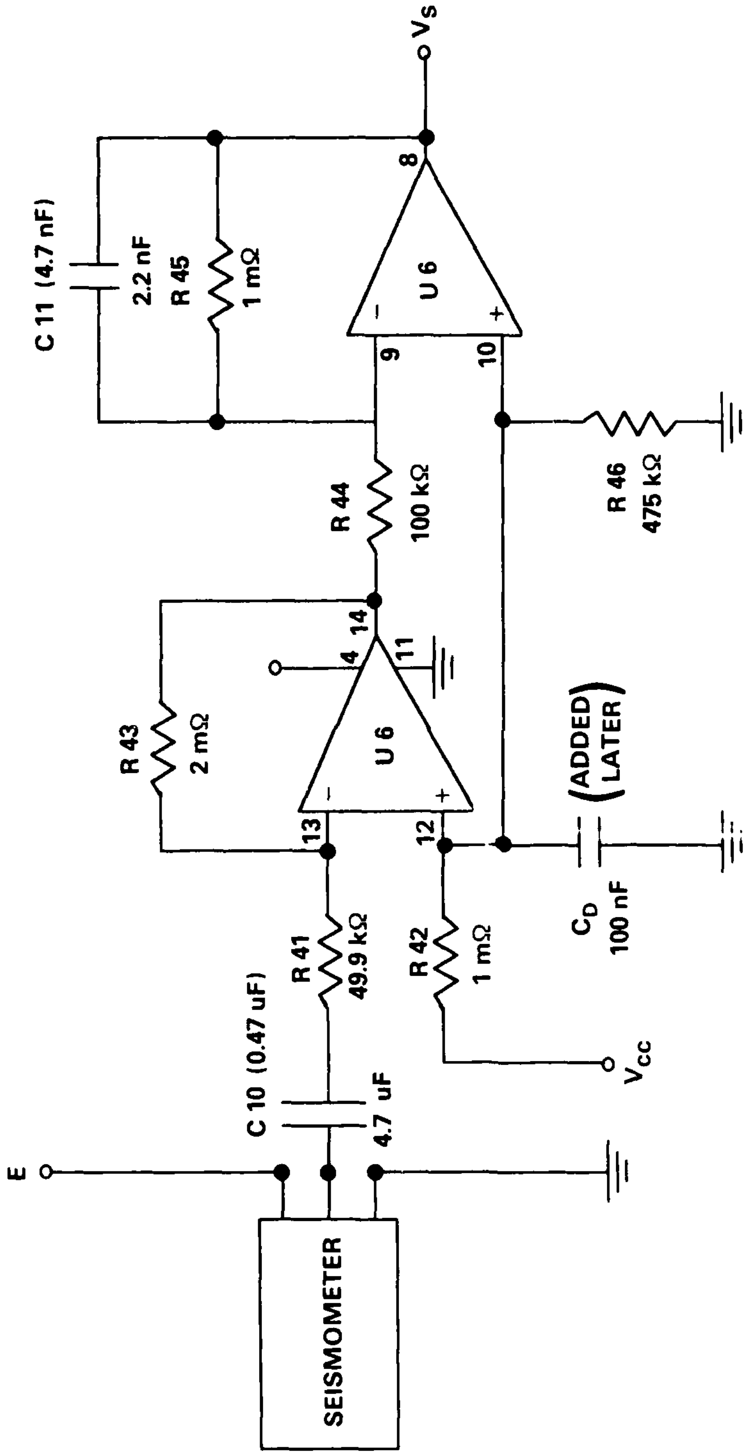

Figure 4.3
SEISMIC CHANNEL ELECTRONICS

	Components				3 dB Points	
	$C_7(\mu F)$	$C_8(nF)$	$R_{39}(k\Omega)$	$R_{40}(k\Omega)$	$f_l(Hz)$	$f_u(Hz)$
desired	-	-	-	-	0.2	25
initial	2.2	33	475	100	0.72	10.2
final	4.7	6.8	1000	200	0.17	23.4

Table 4.1: Magnetic Channel Filter Parameters

	Components				3 dB Points	
	$C_{10}(\mu F)$	$R_{41}(k\Omega)$	$C_{11}(nF)$	$R_{45}(M\Omega)$	$f_l(Hz)$	$f_u(Hz)$
desired	-	-	-	-	0.2→0.5	60→70
initial	0.47	49.9	4.7	1	6.8	33.9
final	4.7	49.9	2.2	1	0.68	72.3

Table 4.2: Seismic Channel Filter Parameters

5. External Communications

The Practice Mine can communicate with the external world via three different devices. These are:

1. the terminal interface,
2. the transmit coil, and
3. the flip-disc displays,

The Slave has total control over the first two. It shares control of the flip-disc displays with the Master, and as such, the displays should be considered separately from the terminal interface and the transmit coil. Of these latter two, the terminal interface communicates the most information.

5.1 Terminal Interface

A Practice Mine can operate in one of two different modes. In one mode of operation, the unit simulates a modern anti-tank mine and is used to train troops. In the second, the unit communicates information to the outside world. To provide the necessary communication link, a computer terminal is used. Two different types of information are communicated through the terminal. The first type consists of data used to ascertain the health of a mine or to determine where problems exist within a malfunctioning unit. Typically, an individual enters a one character code through the terminal keyboard, which is then transmitted to the mine and commands the unit to perform one of a variety of internal self-tests. The mine performs the test and transmits its results back to the terminal, which then displays them. The individual examines the result, and determines if an error associated with the specified test has occurred.

The second type of information is used to update the contents of the non-volatile RAM (NVRAM). As such, the information consists of the self-neutralization time and the fuze parameters. These values are used when the mine is operating during an exercise. The actual method of sending the second type of

information is the same as the first type. That is, an individual enters a value on the keyboard which is then sent to the mine. The mine deciphers the value and stores it in the correct location within the NVRAM and prompts the individual for the next value.

The terminal chosen for use with the Practice Mine is a handheld Termiflex model HT/1000. Data is transferred between the terminal and the mine on two lines; one is used for the transmission of data and the other is used for data reception. Because only two lines exist for the interchange of data, it must be done in a serial manner. The particular interchange format used is RS-232C, with a data transmission rate of 2400 baud. One start bit and one stop bit along with eight data bits are used, with no parity checking performed. The HT/1000s obtained for use with the Practice Mine were purchased with an optional feature which allows for operation at TTL levels (ie 5 volts and ground) on their transmit and receive lines instead of the normal RS-232 levels of ± 12 volts. Because the digital electronics within the mine also operate at TTL levels, no level shifting components were necessary, thus helping to minimize the number of components needed in the unit.

A schematic dia ram of the interface is shown in figure 5.1. Because no level shifting components are needed, electrically the interface is simple. Pin 7 on the Slave microprocessor corresponds to I/O line 4 within port A. This line is configured by the Slave microcode to be an output, as it is used to transmit data to the terminal. Pin 6 corresponds to I/O line 5 within the same port. This line is configured to be an input, as it is used to receive data sent by the terminal. A third line also connects to the terminal. As shown, this line provides for a common ground between mine and terminal. Whenever a terminal is connected and not transmitting data, the RxD line is grounded, pulling pin 6 low. Without a terminal connected, the RxD line is pulled high by the 100kΩ resistor. By sensing the voltage level at pin 6, the Slave microprocessor can determine whether a terminal is present or absent. Based upon this determination, the mine decides upon its mode of operation.

Figure 5.2 shows a Termiflex terminal connected to a Practice Mine. The interface is as simple physically as electrically. The connecting leads of the terminal end in a small black plug, which fits over three pins located at one edge of the mine's printed circuit (PC) board. These three pins correspond to the TxD, RxD and ground lines shown in figure 5.1. PC board traces route these three signals to their correct locations within the mine's electronics. As the figure shows, the mine case must be opened for the terminal to be connected to the mine.

5.2 Transmit Coil

The Practice Mine has the capability to transmit information regarding its health or location. A coil driven by the mine's electronics gives the mine this capability. The range of the transmission is limited to a few meters. However, this limited range is adequate for use in sending status and location information to troops using the mine.

When a Practice Mine is first turned on, its electronics check out the health of the device. If no problems are encountered, the mine then transmits an 8 bit status code in a return to zero frequency shift keyed (FSK) format. The MARK frequency used is approximately 1115 Hz, while the SPACE frequency is about 920 Hz. A transmitted "1" consists of 66 cycles of the MARK frequency followed by 36 cycles of the SPACE frequency, while a "0" consists of 36 cycles of the MARK frequency followed by 60 cycles of the SPACE frequency. A start bit consisting of 100 cycles of the SPACE frequency is incorporated into the transmitted code. The most significant bit of the code follows the start bit. A receiver placed close to the mine can intercept and decode this transmission. If the status word as decoded by the receiver is incorrect or not sent at all, then the receiver can indicate that the mine is malfunctioning.

In addition to this, after a mine has disarmed, it then begins to transmit a 976 Hz tone. This tone can be used as a homing beacon by the troops sent to recover the mine. This feature would be especially useful if a mine is buried or has otherwise been obscured by vegetation or dirt. A receiver would look and act much like a conventional mine detector. Experiments with a prototype receiver indicate that the onset of detectability of a mine transmitting the tone is approximately 5 feet. Note that a mine which is still armed or in an error state does not transmit the tone and as a result could not be found by this means.

Figure 4.1 shows that the coil is located within the mine around the pyrotechnic well. The coil form is 7.5 cm in diameter and 4 cm high. Besides giving support to the coil, it is also used as a support for the inner edge of the PC board. The coil itself consists of 190 turns of 29 guage magnetic wire. Its edges come to within 4 to 6 cm of the edges of the form. The coil geometry and wire used give the coil a nominal resistance of 15Ω and a nominal inductance of 4 mH.

The coil drive circuitry is shown in figure 5.3. To energize the coil and transmit the required information, transistor Q16 must conduct current. To do this, the Slave microprocessor sets pin 4 high. Pin 4 corresponds to line 7 within I/O port A. Modulation of the transmitted signal is accomplished by modulating the state of this line.

To exploit this feature, receivers designed to intercept and decode the status

and locate tones must be available. These will add to the overall cost of the mine training system.

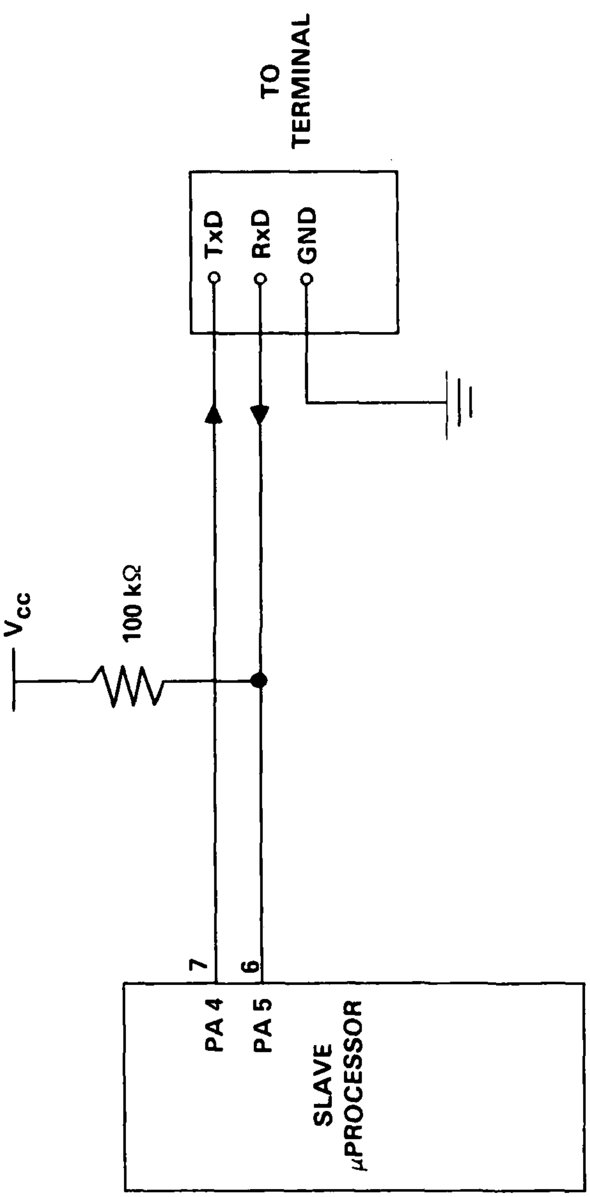

Figure 5.1
TERMINAL INTERFACE SCHEMATIC

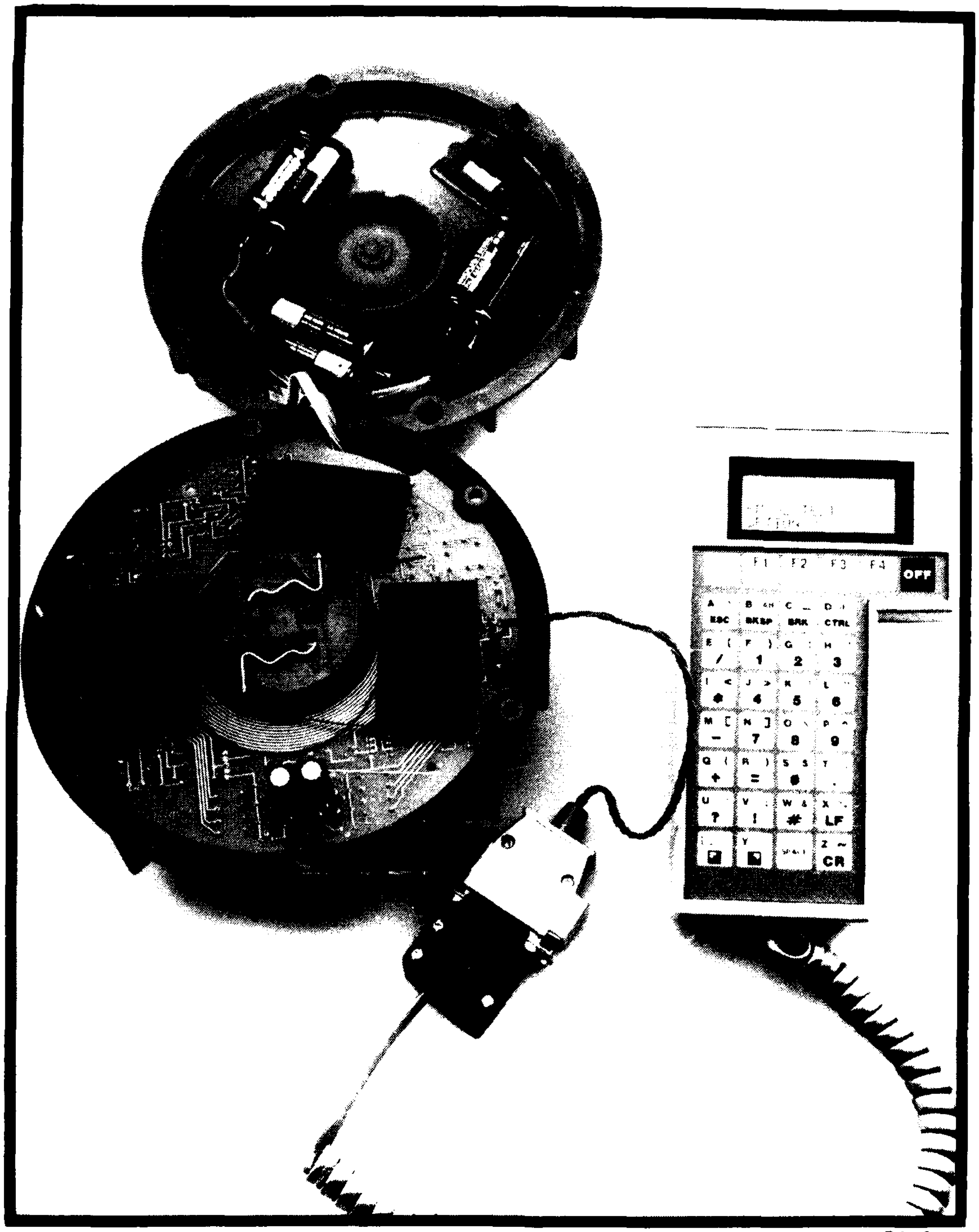

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Figure 5.2

TERMINAL CONNECTED TO MINE

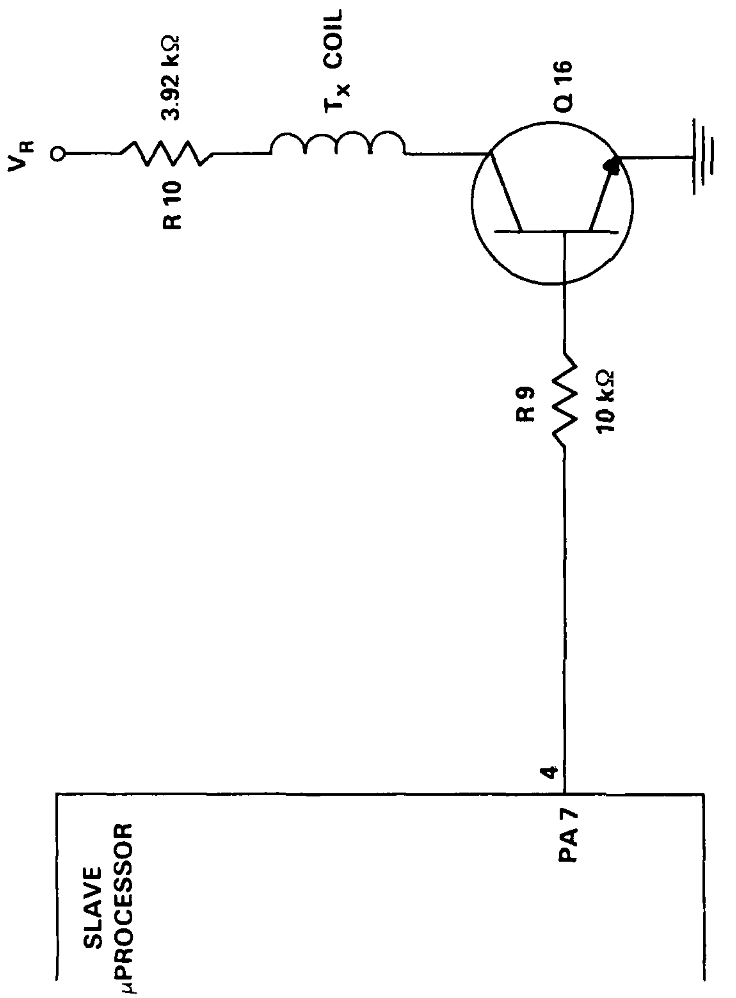

Figure 5.3
COIL DRIVE CIRCUITRY

6. Flip Disc Displays

Each Practice Mine uses four Ferranti-Packard FP30ND flip disc displays as status indicators. This display is an electromagnetic device controlled by switching current through three terminals, SET, COMMON and RESET. A permanently magnetized disc within each display is green in color on one side and red on the other. Current flowing into the COMMON terminal and out the SET terminal flips the disc so that the green side is exposed to view; current flowing into the COMMON and out the RESET terminal exposes the red side. Once the disc has flipped, the current is turned off, conserving the batteries. This ability to provide a constant indication of the status of the mine without consuming any power is the reason the flip disc displays were chosen over other types of visual displays.

Each microprocessor controls two of the four displays. Whenever a processor believes that the mine is disarmed, it drives its two displays so that their green color shows. Whenever it believes that the mine is armed, or when it encounters an error within the unit, it drives its two displays red. The possibility exists therefore, for two of the four displays to be red while the other two are green. In this case, one processor has found an error somewhere within the mine that the other processor cannot locate or one of the two processors has malfunctioned. For the most part however, all four displays should be the same color, indicating that both microprocessors consider the mine to be in the same state.

The display terminals are soldered directly to the PC board. Two of the four are attached to the solder side of the PC board, the other two to the component side. The displays can be viewed from the exterior of the mine through two windows within the walls of the mine case. These windows are located directly above both groups of displays. Each processor controls two displays, one on either side of the board. This arrangement ensures that one group of two displays, showing the state of both microprocessors, is visible regardless of the orientation of the mine.

The drive circuitry for one of the four displays is shown in figure 6.1. The display is denoted D1M for Master display 1. Pin 33 on the Master microproces-

sor corresponds to I/O line 4 within port D, while pin 34 corresponds to I/O line 5 within the same port. When the Master sets pin 33 high, transistor Q5 will turn on and conduct current from bus V_R into the COMMON terminal of D1M and out its RESET terminal to ground. This flips the disc within D1M so that its red side is exposed to view. Similarly, when pin 34 is set high, transistor Q6 will turn on and conduct current from V_R into the COMMON terminal of D1M and out its SET terminal to ground. This exposes the green side of the disc to view.

The displays require a large amount of current to operate. Each display requires a current pulse at least 1.5 ms long with a minimum amplitude of 250 mA to turn its disc. As the device has a nominal resistance of $12\Omega \pm 10\%$, a minimum voltage of 3.3 volts is required to ensure that the disc will flip. This consideration necessitated connecting the displays across the full V_R bus rather than just across V_R to V_C as was done for the smoke charge. Chapter 2 provides further information on power supply considerations.

Figure 6.1 does not explicitly show the drive circuitry for D1S (Slave display 1), D2M (Master display 2), or D2S (Slave display 2). However, this unrepresented circuitry is identical in form and function to the drive circuitry for D1M. The only difference concerns the pins used to control the displays denoted with a "2". Pins 35 and 36 are used on both processors for this purpose. These pins correspond to I/O lines 6 and 7 within port D. The Slave controls D1S with the same lines that the Master uses to control D1M. Those displays denoted with a "1" are attached to the solder side of the PC board, while those denoted with a "2" are attached to the component side. As a result, the "2" displays are visible when the mine is oriented so that the smoke charge points up.

A problem relating to the displays was found on the mine schematic produced by Honeywell. The Honeywell drawing number for this schematic is 40004199, dated January 10, 1986. On this drawing, the SET and RESET markings (S and R respectively) on the flip disc displays have been interchanged. For example, the collector of Q5 is shown connected to the SET terminal of D1M when it actually connects to the RESET terminal. For this drawing to accurately reflect the electronics within the mine, the "S" markings should be changed to "R" and vice versa.

The displays have two considerable drawbacks. The first is the large current draw required to turn the discs. This large draw can lead to sharp drops in supply voltage within the mine. This phenomenum, and its possible consequences are described within Chapter 2 and Appendix A. The second drawback is mechanical in nature. The discs have a tendency to fall out of their housing when the displays are handled roughly, rendering the displays useless.

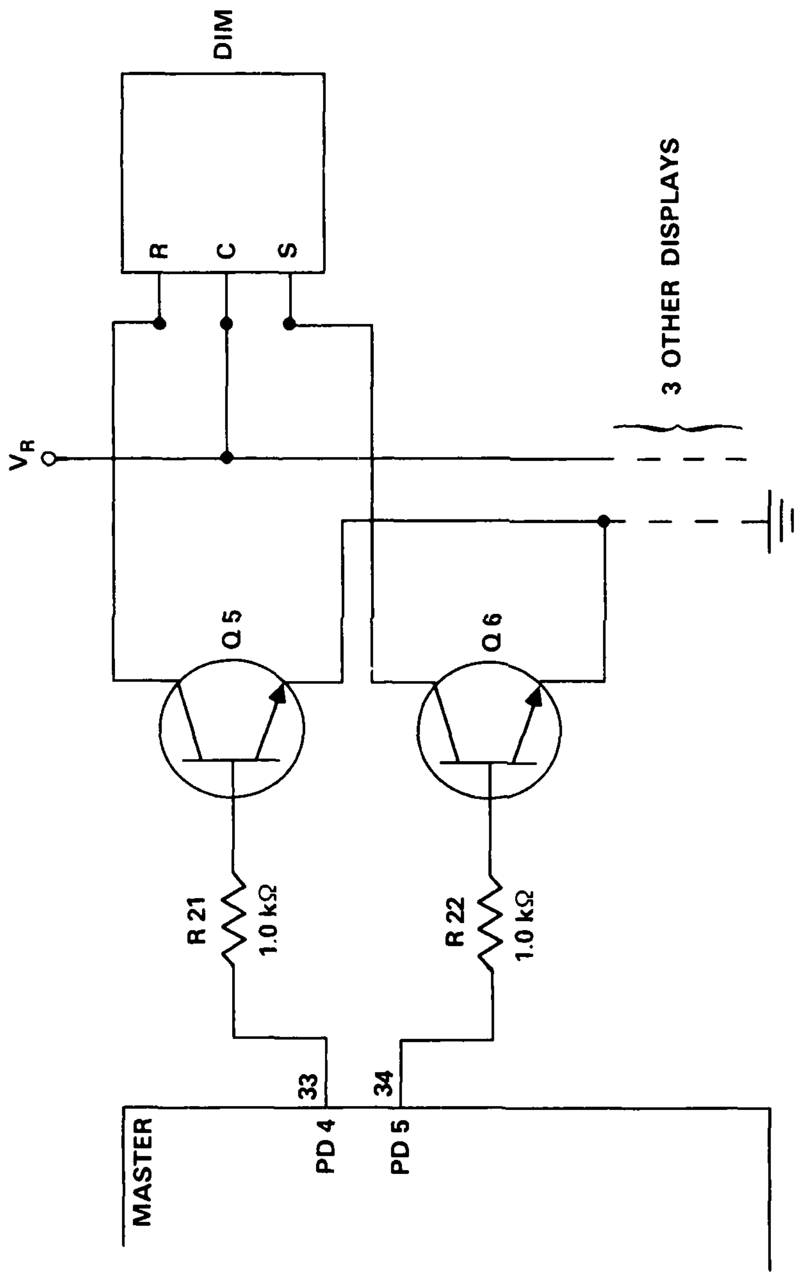

Figure 6.1
DRIVE CIRCUITRY FOR MASTER DISPLAY 1

7. Firing Chain Circuitry

Safety considerations were of prime importance during the design of the Practice Mine and in particular the firing chain circuitry. This circuitry is responsible for the ignition of the smoke charge. The smoke charge is the only hazardous component of the Practice Mine. As such, the firing chain circuitry was designed to reflect the safety criteria applied during the design of the entire mine. These criteria maintained that a single component failure and improper operation, or a two component failure and correct operation would not be sufficient for accidental ignition of the smoke charge.

Figure 7.1 shows the three parts of the firing chain circuitry. These three are:

1. the drive circuitry for relay 1,

2. the drive circuitry for relay 2, and

3. the ignition current path.

Both relays must be activated in order to ignite the squib. As a single microprocessor controls only one of the two relay drive circuits, both units must participate actively in the ignition of the smoke charge, thus ensuring that a single malfunctioning microprocessor could not cause an accidental ignition.

The Master microprocessor controls the drive circuitry for relay 1 through pins 31 and 32. These correspond to lines 2 and 3 of I/O port D. For relay 1 to be activated, current must flow from node V_R through the relay coil within RLY1, and through transistors Q1 and Q2. In order for Q1 and Q2 to conduct this current, the voltage at their bases must be greater then that at their emitters. For this to occur at Q2, pin 31 must be in a high or "1" state. For a similar situation to exist at Q1, transistor Q13 must also be conducting. As a result, pin 32 must be in a low or "0" state. Therefore, of the four possible states of the two pins, only one will activate the relay. This feature, particularly the need for definite and different states on the two pins, helps to decrease the possibility of accidental relay activation by a malfunctioning processor. The

Slave microprocessor controls the drive circuitry for relay 2 in exactly the same way.

Diodes D2 and D3 are turned off when current is flowing through and activating the two relays. They conduct only when the activation current is turned off; then the diodes shunt any flyback voltage generated across the relay coils. They do not play a role in activating the relays.

The ignition current path was also designed to prevent accidental ignition caused by component failure. Figure 7.1 was drawn with the relay armatures in their normally open position and the Safe/Arm switch in the Arm position. The Safe/Arm switch consists of two poles and as such performs two functions. One pole shorts the squib terminals when the switch is in the Safe position and removes this short when the switch is in the Arm position. The other pole pulls Slave pin 28 (line 0 of I/O port C) high when the switch is in the Safe position, and low when the switch is in the Arm position. As a result, the mine is able to determine the position of the Safe/Arm switch.

Figure 7.2 is a simplified view of figure 7.1 showing only the ignition current path. The Safe/Arm switch is in the Arm position with the relay armatures in their normally open position. This is the normal state for the ignition current path when the mine is armed. The squib terminals are shorted and the two power supplies, V_C and V_R, are isolated from the squib by the two open relays. Note that the voltage at the squib terminal denoted by V_{SQ} will be pulled to ground by one of the two 40kΩ resistors. The voltage at this terminal is monitored by the digital electronics through the use of the analog to digital converter (ADC). If a fault develops within the ignition current path, this voltage will rise. The digital electronics will sense this rise and cease operation.

Figure 7.3 shows the state of the ignition current path when the microprocessors activate the relays. Current will flow from V_R, through the Safe/Arm switch and the squib, to V_C. Some current will also flow through the two 40kΩ resistors, but this will be quite small compared to the current flowing through the squib because the squib resistance is much smaller than that of the two resistors. Effectively, 3 volts, the difference between V_R and V_C, is placed across the squib resistance of approximately 1Ω.

Figure 7.4 shows the state of the ignition current path if both relays accidentally close while the Safe/Arm switch is in the Safe position. The closure of the relays could be due to inadvertant activation by malfunctioning processors or to physical damage to the armatures. V_{SQ} will rise to V_C. The V_R power supply will be disconnected from the squib and the squib terminals will be shorted together because of the Safe/Arm switch. As a result, while currents will flow from the two supplies, they will flow through the two 40kΩ resistors to ground. No current will flow through the squib, and it will not be accidentally ignited even

though two components malfunctioned.

Figure 7.5 shows the state of the ignition current path if relay 2 accidentally closes while the Safe/Arm switch is in the Arm position and relay 1 remains open. V_{SQ} will rise to V_R. Any current that flows from V_R will be limited by the two 40kΩ resistors and shunted to ground by them. The squib terminals will be shorted together through relay 1. As a result, no current will flow through the squib and it will not be accidentally ignited.

Figure 7.6 shows the state of the ignition current path if relay 1 accidentally closes while the Safe/Arm switch is in the Arm position and relay 2 remains open. V_{SQ} will rise to V_C. Current will flow through the squib, but it will be limited by the 40kΩ resistor to 75 μA or less. The minimum current necessary for ignition is approximately 500 mA. As a result, the squib will not be accidentally ignited if this situation occurs.

The above scenarios illustrate that accidental ignition of the smoke charge will not occur in the event of a one component failure. The Practice Mine poses the greatest hazard when power is first applied. Correct procedure for turning on a Practice Mine demands that the Safe/Arm switch be in the Safe position prior to applying power with the On/Off switch. If this is followed, a two component failure will not cause an accidental ignition of the smoke charge upon application of power. However, if the Safe/Arm switch is in the Arm position upon application of power, then only a one component failure could be tolerated without accidental ignition. At the crucial time of power application then, a two component failure without a procedural error or a one component failure with a procedural error can be sustained without accidental ignition of the smoke charge. At any other time, a one component failure can be sustained without accidental ignition.

Appendix B describes a number of tests performed to validate the design of the firing chain circuitry.

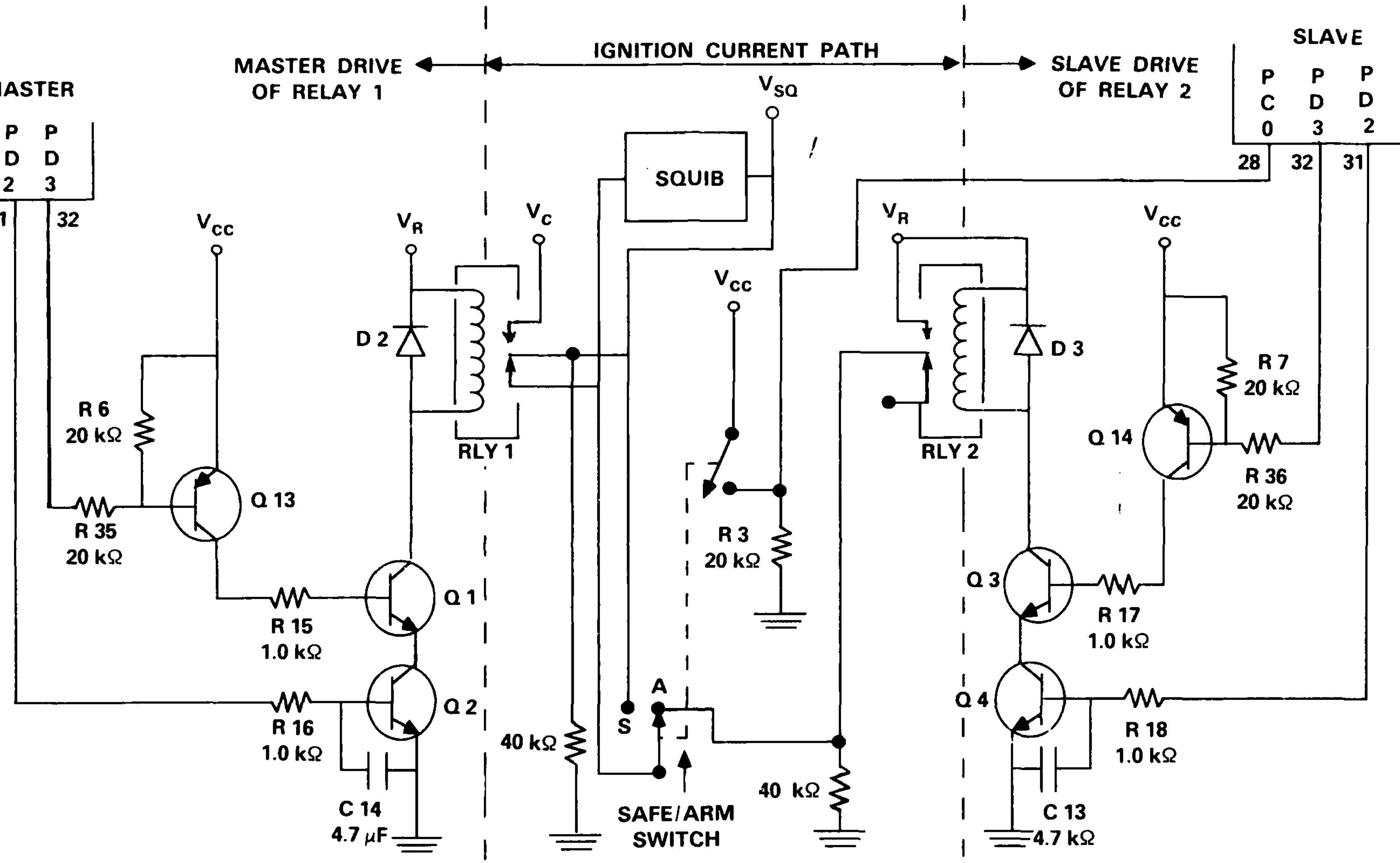

Figure 7.1

FIRING CHAIN SCHEMATIC

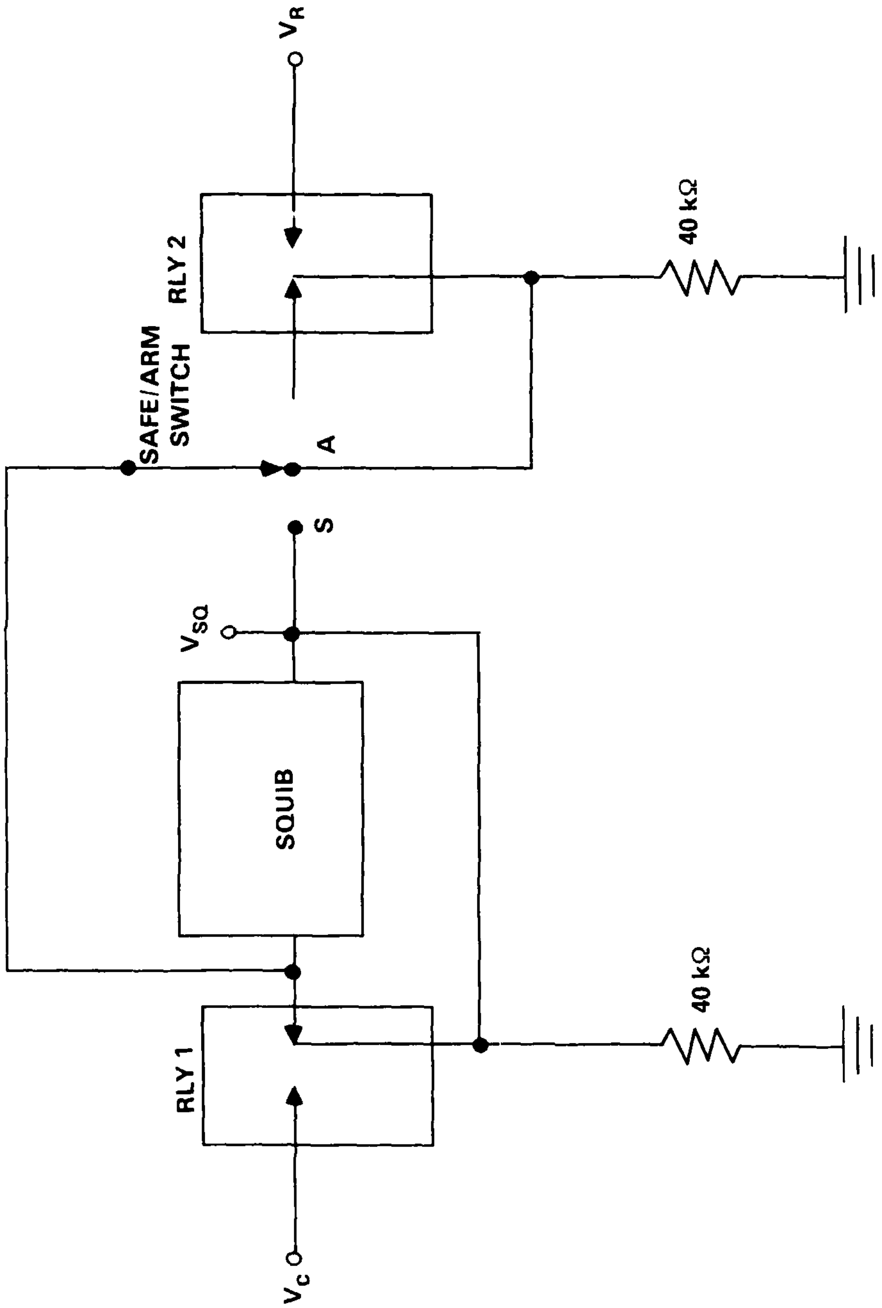

Figure 7.2
IGNITION CURRENT PATH-ARMED

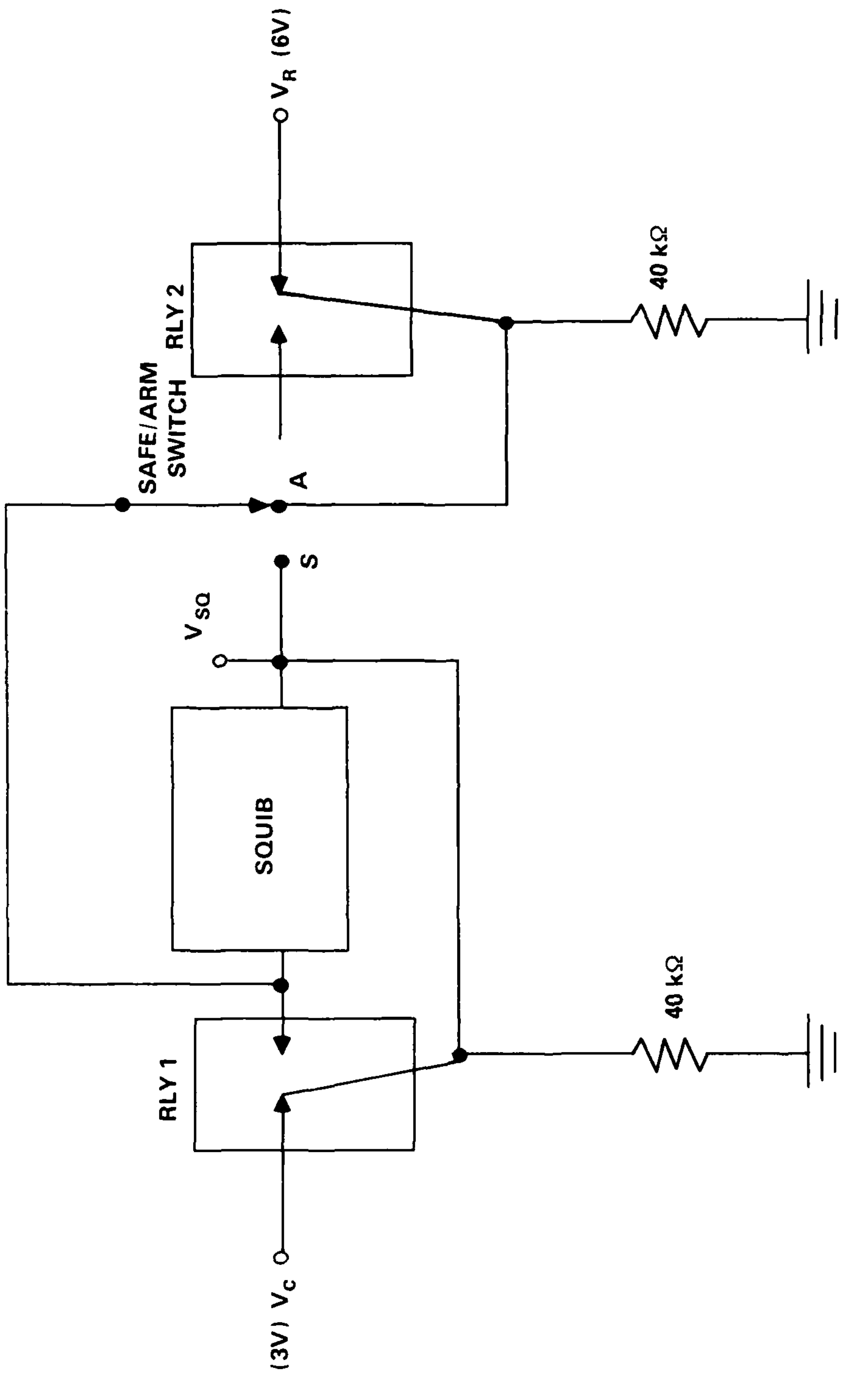

Figure 7.3
IGNITION CURRENT PATH-FIRING

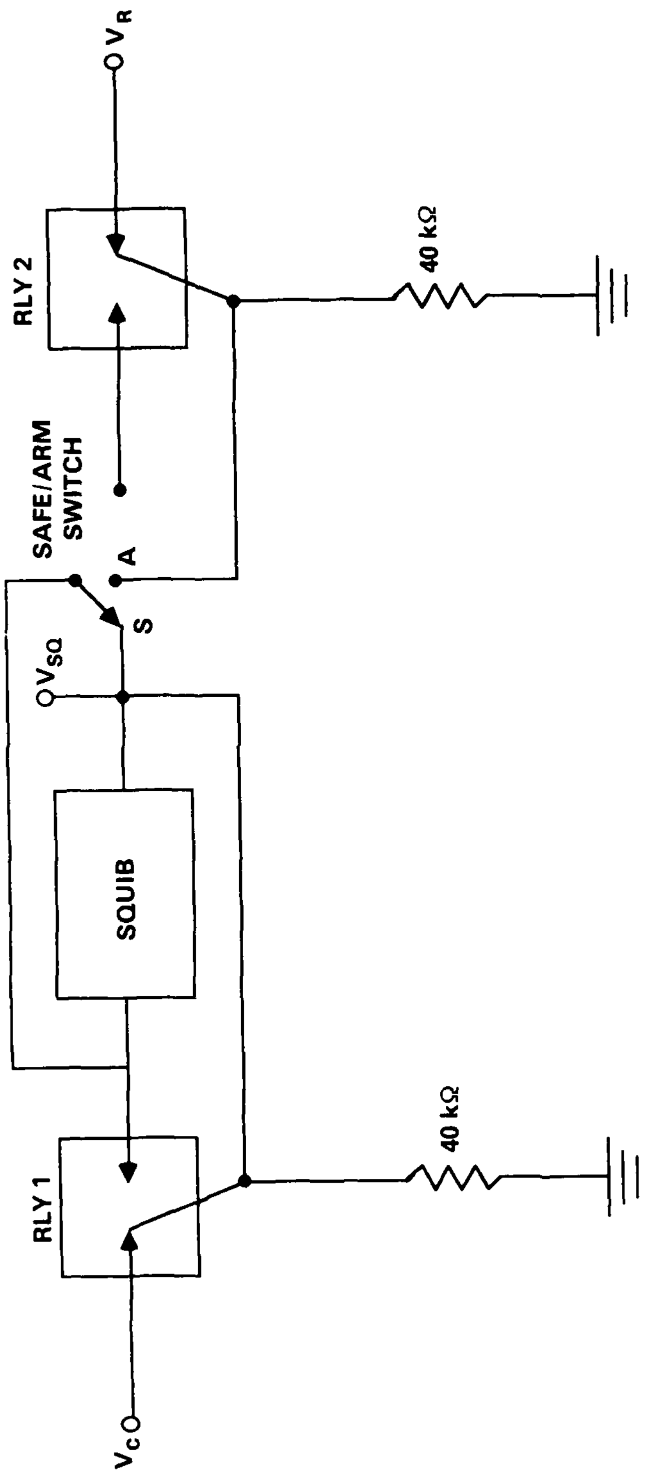

Figure 7.4

FAILURE OF BOTH RELAYS

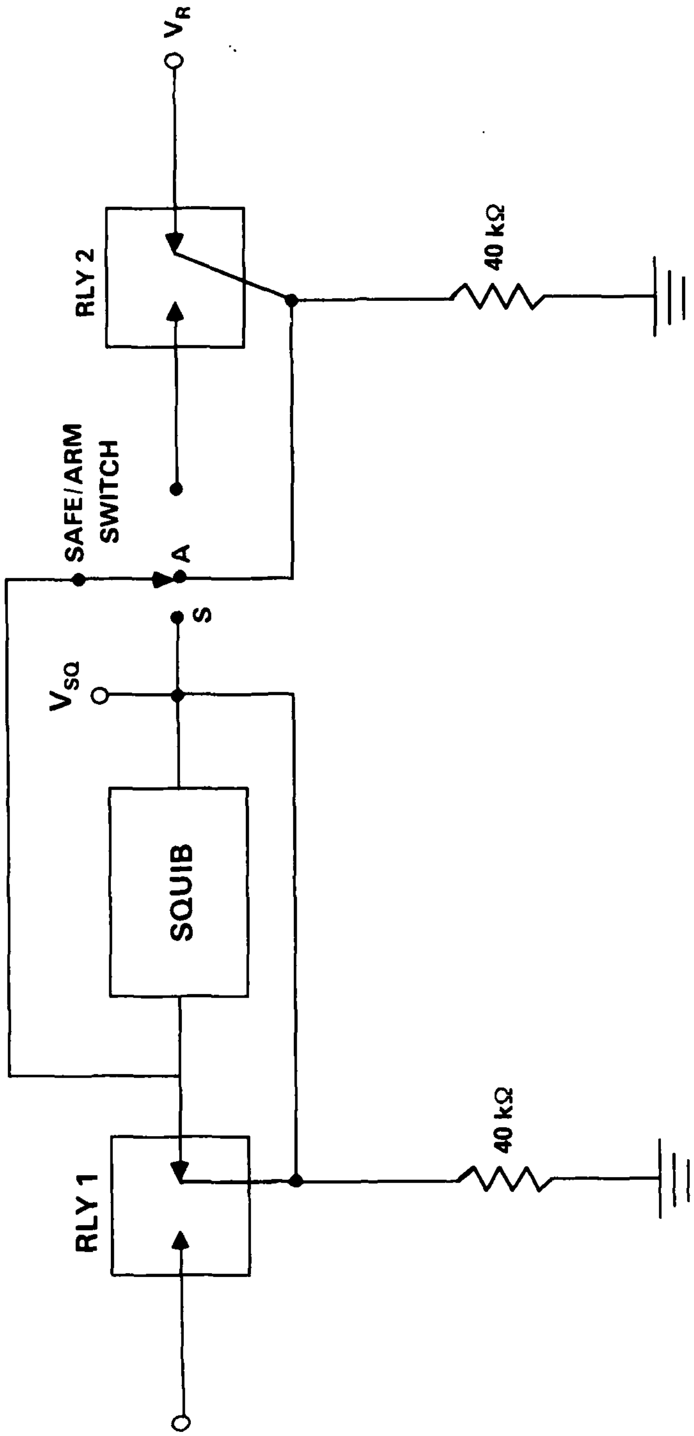

Figure 7.5
FAILURE OF RELAY 2

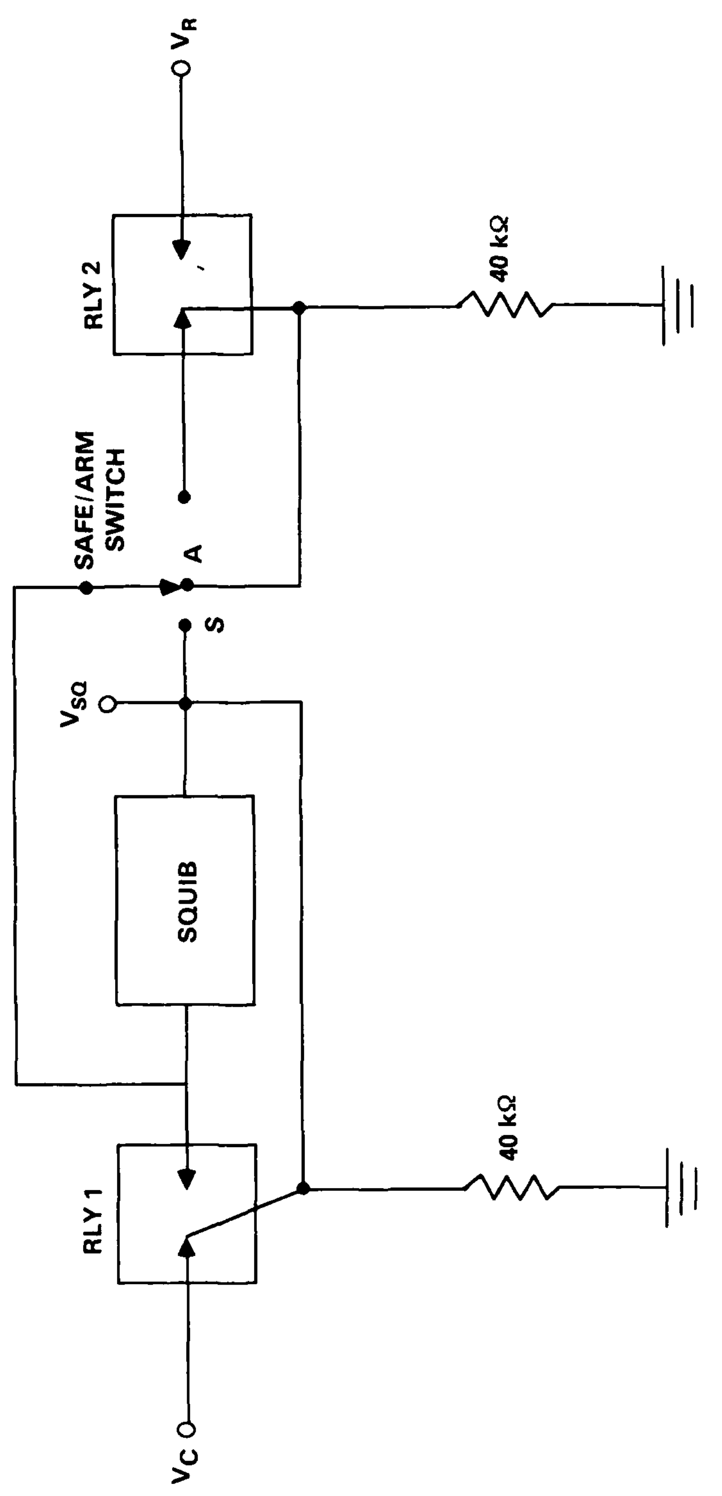

Figure 7.6
FAILURE OF RELAY 1

8. Smoke Charge

The smoke charge (see figure 8.1) is approximately 8 centimeters high and 6 centimeters in diameter. The aluminum cannister is painted a light blue colour. A label featuring a black stripe and the words "CHARGE SMOKE SPOTTING" in white letters, along with four large X's and a lot number, also in white letters, is affixed to the side of each charge. A rubber O-ring is located around the rim of the cannister, approximately 3 centimeters from its top. This ring seals the space between the smoke charge and mine wall when the charge is inserted into the mine, preventing water from shorting the electrical contacts at the bottom of the smoke charge. The side of the cannister between the O-ring and the cannister top has been knurled to aid in gripping the charge during insertion or removal.

The smoke vents through a hole in the center of the top of the cannister. The venting hole of an unignited charge is covered with a piece of plastic tape to keep dirt and water out of the cannister. Two brass contact pins protrude from the bottom of the cannister as shown in figure 8.2. These pins serve two purposes. First, they complete the firing circuit, enabling the mine to fire the smoke charge. Second, they lock the charge into place within the mine, ensuring that it cannot fall from the mine during use. To lock the smoke charge into place, the unit is first inserted into the mine's pyrotechnic well until the brass contacts pins touch the bottom of the well, then it is rotated. This rotation first aligns the contact pins with slots in the bottom of the well, then it locks the pins into place within these slots.

The smoke charge protrudes approximately 2 centimeters above the top of the mine when it has been inserted and locked into place. The knurling mentioned previously is still accessible however, and allows for enough of a grip on the smoke charge to be able to insert and remove it with minimal trouble.

Electrically, the smoke charge is very simple. The squib within it can be considered a resistive element with a value of approximately 1Ω. The squib used is a DND C–2 igniter requiring approximately 500 mA of current flow through it for initiation. When sufficient current is present within the squib, the igniter flames and starts a primed cambric target burning, which in turn ignites the

smoke-making composition. The smoke-making compound is SK-351-J. The smoke is yellow in color and lasts for approximately 15 seconds.

The smoke charge suffers from a number of drawbacks associated with its insertion into and removal from a mine. The protruding top of the smoke charge crushes when a vehicle drives over the top of a surface emplaced Practice Mine. The crushed cannister is very difficult to remove from the mine, and can be potentially dangerous if the charge was not ignited by the mine when the vehicle contacted it. Also, the protruding top is still quite smooth, even with the added knurling. As a result, in situations where a smoke charge fits tightly into a mine, the smoke charge is difficult to rotate.

Tests performed to determine the characteristics and performance of the smoke charge are described in Appendix B. Chapter 7 describes the circuitry used to ignite the smoke charge.

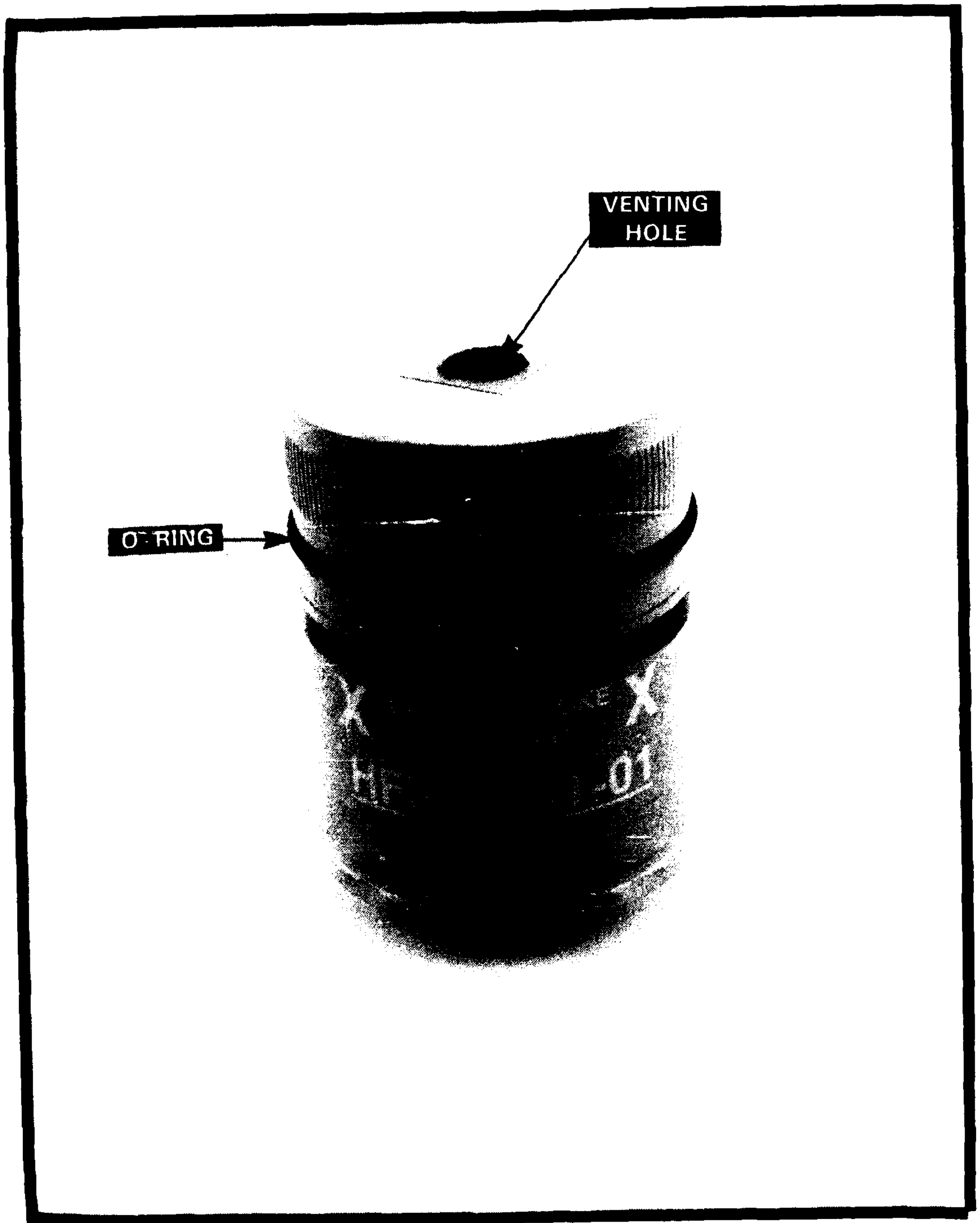

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Figure 8.1

TOP VIEW OF SMOKE CHARGE

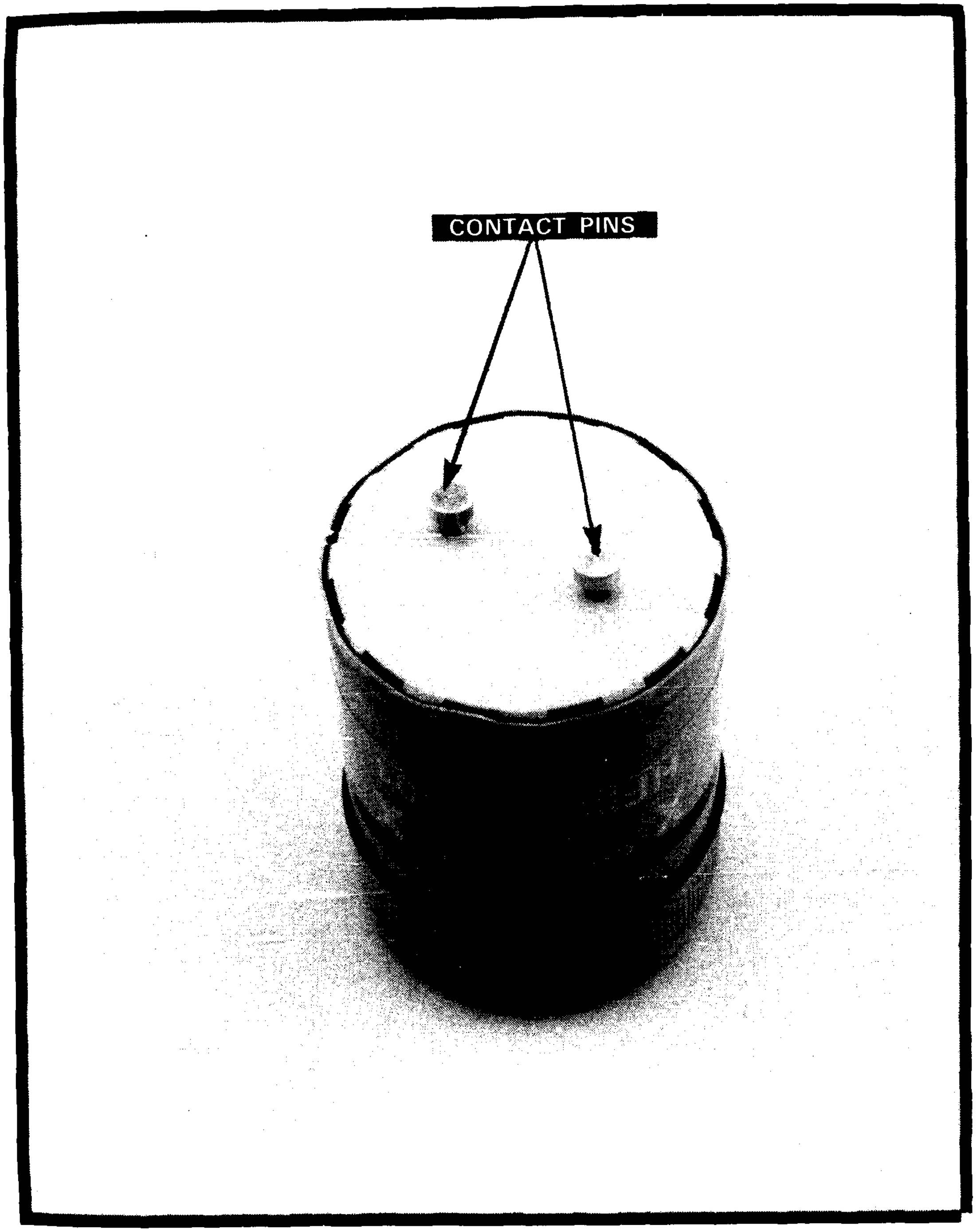

Figure 8.2

BOTTOM VIEW OF SMOKE CHARGE

9. Conclusion

This report described the hardware within the Practice Mine. A full understanding of the way the Practice Mine works is possible when this report and the software report [1] are consulted.

9.1 Recommendations

In October 1987, representatives of DRES ODG and DMER met to discuss the next phase of development of the Practice Mine. At that time, the following action items and recommendations were discussed:

1. the case should be redesigned to permit easier battery access and incorporate more robust battery holders,

2. a replacement for the processors must be found as no variant exists which has a specified operating temperature below 0°C. (The SOR (Statement of Requirements) for the Practice Mine demands that the unit operate at -15°C). A possible candidate is the MC68HC811.

3. ADC variants are available which operate at -15°C and should be used in any additional Practice Mine units,

4. NVRAM variants are available which operate down to -40° and should be used in the future,

5. variants of the Intersil battery check IC are available that operate down to -55°C and should be used in any follow-on versions of the mine,

6. the height of the smoke charge cannister should be decreased so that it does not protrude from the top of the mine and hence cannot be crushed, and in conjunction with this, a tool should be designed which attaches to the top of the shortened cannister and allows for its insertion or extraction,

7. the flip disc displays should be replaced with more robust visual indicators, such as LEDs (light emitting diodes),
8. a troop trial involving the initial 200 Practice Mine units, which originally was scheduled for fall 1987 and then postponed until 1988, must take place soon in order to obtain feedback from the users of the Practice Mine,
9. temperature testing of the Practice Mine must be done,
10. the transmit coil features should be removed.

10. Bibliography

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Appendix A
Power Consumption Tests

The DRES Practice Mine is powered by six AA batteries. When a mine is on, these batteries become drained of their energy, eventually rendering the unit inoperable. The time elapsed before this occurs, a mine's useful life, must be determined prior to its acceptance for use by the Canadian Forces.

Before attempting to determine a value for the useful life of the mine, a definition of what constitutes useful life must be decided upon. A mine will operate in either the armed or disarmed state until it detects an error condition, at which time the mine halts operation. One such error condition occurs when the voltage on the bus supplying the digital electronics with power falls below 4 volts. Because this error condition is linked directly to power consumption, the time taken for the voltage to fall to this level will be regarded as the useful life of the mine. Two experiments were performed to determine this time.

A.1 Experiment 1

In the first experiment, six mines were turned on and left running until the batteries were exhausted. At intervals during this time period, the voltage on the bus supplying power to the digital electronics was measured. The useful life of the mine was then determined by noting when the voltage on this bus fell to 4 volts. This particular experiment was performed on three separate occasions with the same six mines.

Figures A.1 to A.6 show the results of this experiment. The first set of voltage measurements is marked with a cross. The second set is marked with an x and the third set is marked with a triangle. Note that the third set of measurements ended after 240 hours regardless of the value of the bus voltage. This interruption was unavoidable; however, the measurements gathered to that time are still useful.

In all cases, the bus voltage remained above 4 volts for at least 216 hours or 9 days. In all but three cases, the mines lasted for at least 240 hours or 10 days.

The three exceptions can be found in:

1. the first set of measurements made for mine 3 (marked with crosses on figure A.2),

2. the third set of measurements made for mines 6 and 9 (marked with triangles on figures A.3 and A.6).

However, these exceptions may not contradict the conclusion that the minimum useful life of the Practice Mine is 240 hours. In the case of mine 3, at the beginning of the first set of measurements, the terminal voltages of its batteries were below those used for the second and third sets of measurements. Thus, the time taken for the batteries to fall to the 4 volt level was shorter in the first set than the second or third. The batteries used in the first measurement were partially drained by other tests done to mine 3 immediately prior to the endurance test. As a result, the terminal voltage of one AA cell in mine 3 at the start of the first set of measurements was only approximately 1.42 volts. A "fresh" AA cell normally has a terminal voltage of 1.55 to 1.6 volts. This terminal voltage would give a starting V_{CC} similar to that recorded at the beginning of the second and third sets of measurements. These last two sets of measurements indicate that the bus voltage would have remained above the 4 volt level for at least 240 hours.

Mines 6 and 9 were discovered to be going through a transition to the power failure error condition when the bus voltage was measured at the 240 hour mark. This transition, which will be discussed further later, is marked by a sudden large current draw by the flip disc displays. This draw, if sustained, rapidly drops the supply voltage and also heats the displays. When the measurement showed a low voltage on the supply bus, the displays were examined and found to be hot. This indicates that the batteries in these units did in fact last until approximately the 240 hour mark before dropping to the 4 volt level.

In a number of other cases (the first set of measurements for mines b, 6, and 8 for instance), the supply voltage remained above the 4 volt level for more than 264 hours, or 11 days. However, enough exceptions to this were found to indicate that although some mines may operate for longer periods of time, the useful life of the mine found during this experiment was 240 hours.

As mentioned previously, a power failure error occurs whenever the voltage on the bus supplying power to the digital electronics falls below 4 volts. More specifically, the ICL battery check IC senses when the bus voltage reaches 4 volts and signals the two microprocessors. When this occurs, the microprocessors recognize the signal and run that portion of their microcode program associated with error conditions. This microcode directs the processor to turn its flip disc displays to

red, and then to halt operation. The flip disc displays, when activated, sink a great amount of current. If the batteries have sufficient reserve capacity, they will source this current without their terminal voltage falling greatly. The displays will flip to expose the red half of the disc and, following this, the microprocessor will stop operating. However, if the batteries do not have enough capacity, the supply voltage will fall substantially, causing the processor to malfunction. The current draw will continue unabated, and will heat the displays and their driving transistors. Eventually, either the terminal voltage falls low enough, or the large current draw so heats the transistors driving the displays that these transistors turn off, and hence stop the current draw which originally caused the problem. This allows the batteries to stabilize and possibly recover. Evidence of this fall and recovery behaviour can be seen most vividly in figure A.1.

No serious complications arising from this behaviour were seen during the first experiment. However, the possibility exists for the processors to flag the wrong error state after the batteries have recovered. The cause of this behavior is low battery voltage which corresponds to a microprocessor state of 101 (see tables 3.2 and 3.3). However, the voltage recovery will reset the processors. Immediately after the processors are reset, they perform their internal self-checks, which includes determining the position of the Safe/Arm switch. In this instance, the switch will be in the Arm position. However, the control program demands that the switch be in the Safe position when the processors are reset. As a result, the processors will flag a procedure or 110 error. This could lead to confusion.

A.2 Experiment 2

The second method of determining the useful life of the mine involved measuring the total current drawn by a mine. Once this value was determined, the useful life was calculated by dividing the total capacity of the batteries by the current draw. The current measurements were made by inserting an ammeter in series with the three supply buses. A mine goes through four different states when operating. These are:

1. the wait for arm state, which occurs after the mine has been turned on and before its Safe/Arm switch is thrown to the Arm position,

2. the countdown to arm state, which occurs for 10 minutes after the Safe/Arm switch is placed in the Arm position,

3. the armed state, which occurs after the above mentioned 10 minute wait has expired and before the mine either fires or the self-neutralization time expires, and

4. the disarmed state, which occurs after the mine either fires or the self-neutralization time expires.

The power consumed is not the same in all four states. As a result, the current measurements have to repeated during each one.

Large current variations occur as the mine switches from one state to another. These variations are caused primarily by the large current draw needed to flip the disc displays. The magnitude of the peak current draw can be determined while measuring the quiescent currents through the use of a peak holding ammeter. Only one such meter was available during the experiment. As a result, the peak currents in each of the three supply buses had to be measured separately. A fourth measurement of the quiescent currents only was also made.

Tables A.1 through A.4 show the values measured for the quiescent current. The measurements have differing precisions because the ammeter scale had to be set to accommodate the peak currents which often were much larger than the quiescent ones. As expected, the current in the V_C bus was small in all four states. The V_C bus will carry a substantial amount of current only when the smoke charge squib is fired. For the rest of the time, the V_C voltage is monitored as part of a check of the integrity of the firing chain. As a result, only current associated with leakage into the analog to digital converter can be expected. The values found were on the order of this leakage current.

The current values measured in the V_R bus were also expected. The V_R bus will carry current in three different situations; these occurring when the smoke charge squib is fired, when the flip disc displays turn and when the locate coil is energized. None of these three situations occur when the mine is in the wait for arm, the countdown to arm or the armed state; therefore the current should be zero. However, the locate coil is being pulsed when the mine is in the disarmed state. The 755 μA average current value measured was not surprising for this situation.

The current in the E (V_{CC}) bus supplies the electronics within the mine. The expected value can be determined by adding together the current drawn by each device powered by this bus, as specified by the manufacturer of the device. Table A.5 lists the devices powered by the E bus along with an estimate of the current drawn by each, as specified by the device manufacturer. Minimum and maximum values are given unless only a nominal value was specified, in which case it was listed in both columns.

The type of microprocessor used in the mine has three different modes of operation; namely, the running, waiting for an interrupt and the halted mode. Different quantities of power are consumed in each of the three modes. When the mine is in the countdown to arm, armed or disarmed state, the microprocessors

are operating in a combination of the running and waiting modes. As a result, the power consumed, and hence the current drawn by the processors is difficult to estimate. However, when the mine is in the wait for arm state, both processors are operating in the running mode. Because of this, the E bus current draw is easily estimated. As a result, the comparison between the values measured in the E bus and those calculated will be made for this state only.

The NVRAM has power applied to it for only a short time after a mine is first turned on. Because of this, it has no effect on the quiescent current draw and is ignored when calculating the current draw in the E bus.

As table A.5 shows, the E bus current draw could range from 9.65 to 14.10 mA. The average current measured in the E bus during the wait for arm state was determined to be 13.74 mA, within the range calculated. This indicates that the measurements made in this bus were reasonable and will be considered to be valid for each of the four states.

The time a mine spends in the wait for arm state and the countdown to arm state is 2 and 10 minutes respectively. A mine will spend the overwhelming majority of its life in either the armed or disarmed state. When armed, the mine draws approximately 7.7 mA of current. The manufacturer of the alkaline cells used by the mine specifies a cell capacity of 1700 mAh (milliamp-hours). Thus, a mine should last for about 221 hours or just over 9 days. The endpoint voltage associated with this 1700 mAh figure is not stated explicitly. As described previously, a mine will fail when the supply voltage reaches 4 volts, or 1 volt per cell. During the armed state, the resistance seen by a single cell is approximately 195Ω. With this nominal resistance, the manufacturer's information states that the 1 volt endpoint voltage would be reached in 243 hours, or just over 10 days.

When a mine has disarmed, a locate tone is transmitted in an attempt to facilitate recovery of the unit. The current drawn by the mine when disarmed totals approximately 8.1 mA, suggesting that the mine will die quicker upon disarming than if it remained armed. However, the standard deviations of the E bus measured currents were such that more current may be drawn in the armed state than in the disarmed one. Because of this, the second experiment suggests that the useful life of the mine is 10 days, regardless of operating state.

Tables A.6 through A.9 show the peak currents measured during the second experiment. The current in the V_R bus flips the disc displays during three of the four transitions. (In the transition from count to arm to armed the displays are not changed). As described previously, the current required to flip the displays is quite large. In all cases, it was measured to be greater than 500 mA. The effects of this large draw have already been discussed. The values measured in the other buses are not surprising, and for the most part can be attributed to switching transients within the digital electronics.

A.3 Conclusions

Both experiments demonstrated that the DRES Practice Mine has a useful life of at least 9 and likely 10 days. Note that the experiments were conducted indoors at an ambient temperature of 20°C. Other tests will have to be done to determine its useful life at other temperatures.

Figure A.1: Mine b – Supply Voltage vs. Time

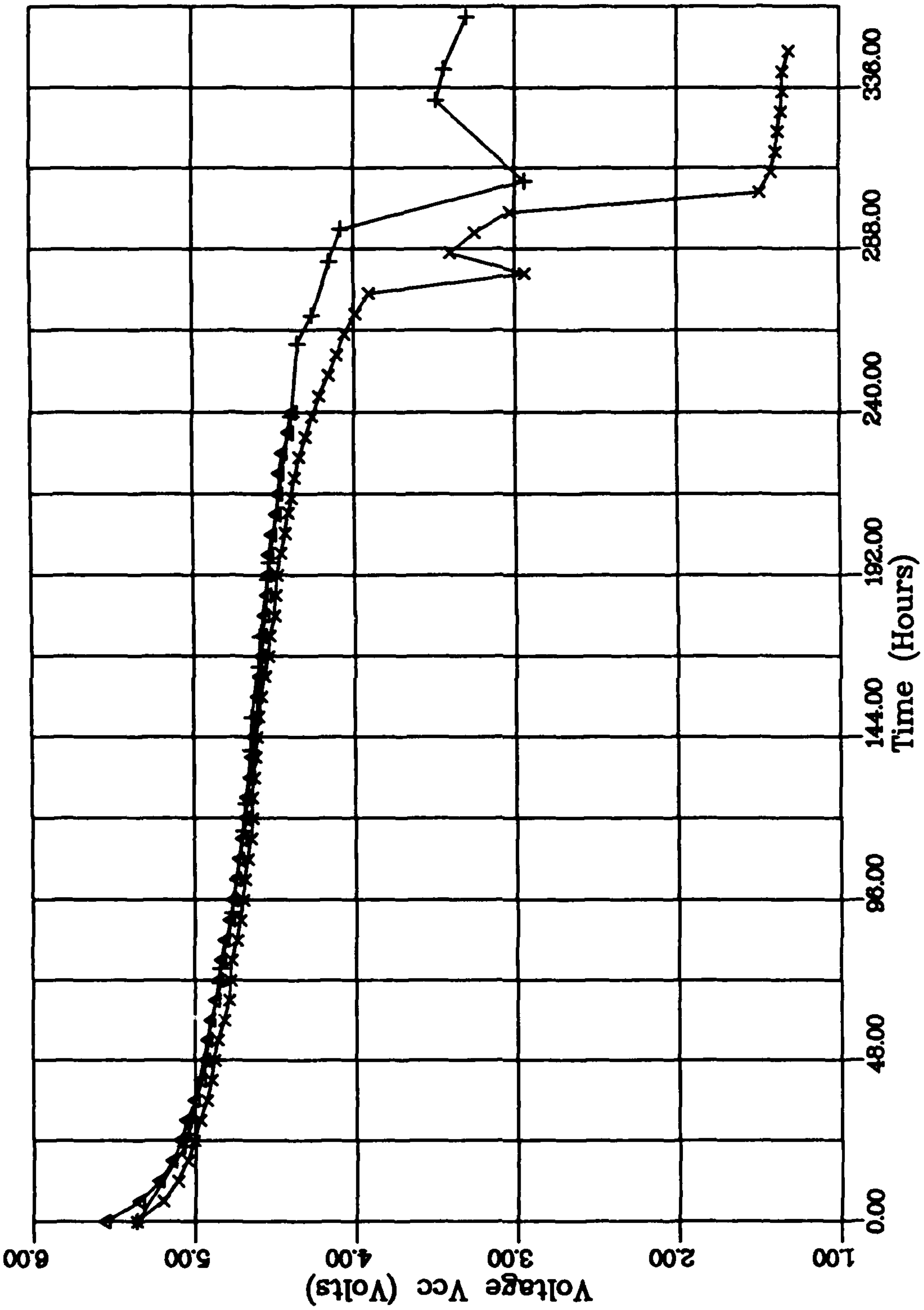


Figure A.2: Mine 3 – Supply Voltage vs. Time

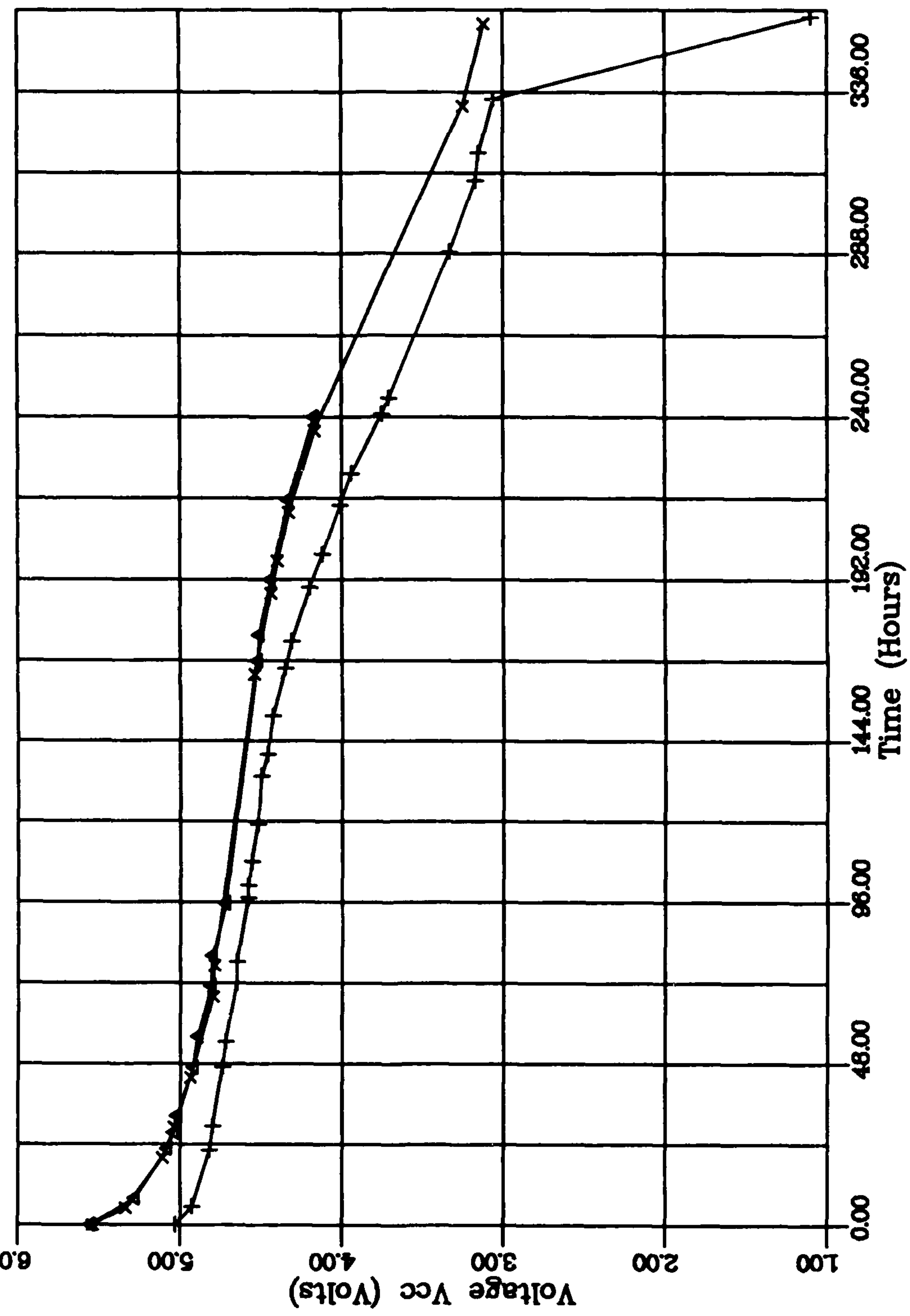


Figure A.3: Mine 6 — Supply Voltage vs. Time

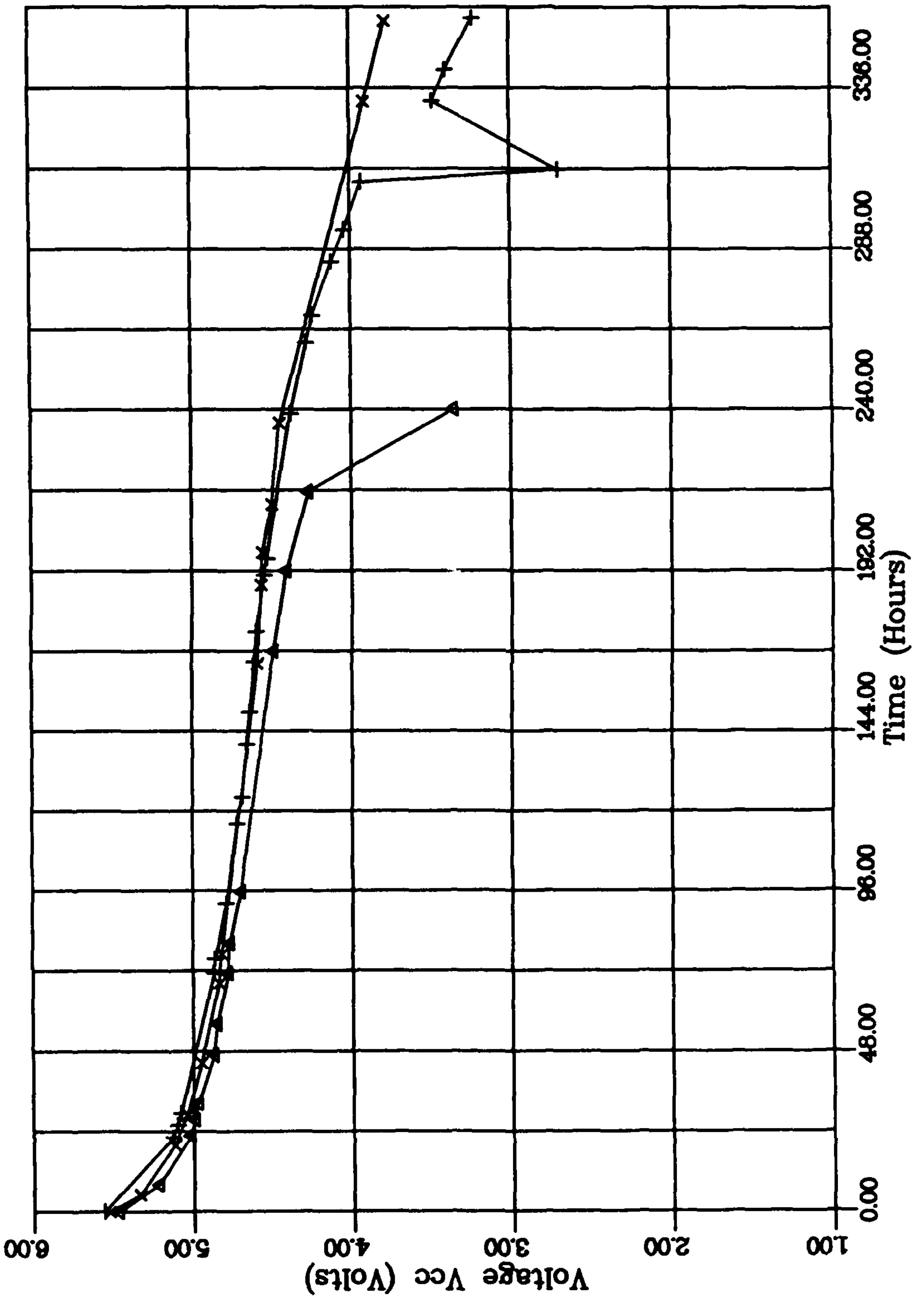


Figure A.4: Mine 7 – Supply Voltage vs. Time

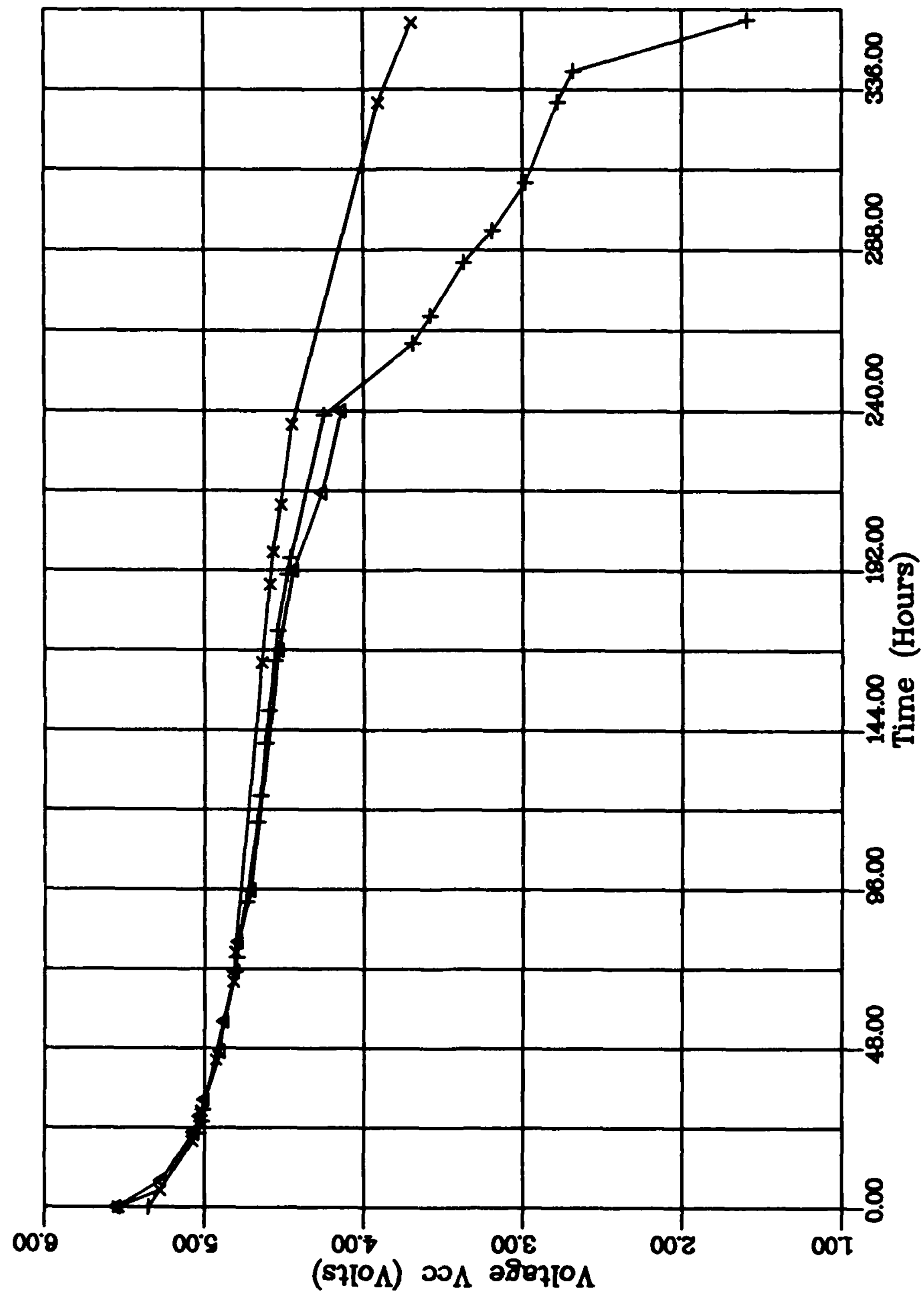


Figure A.5: Mine 8 – Supply Voltage vs. Time

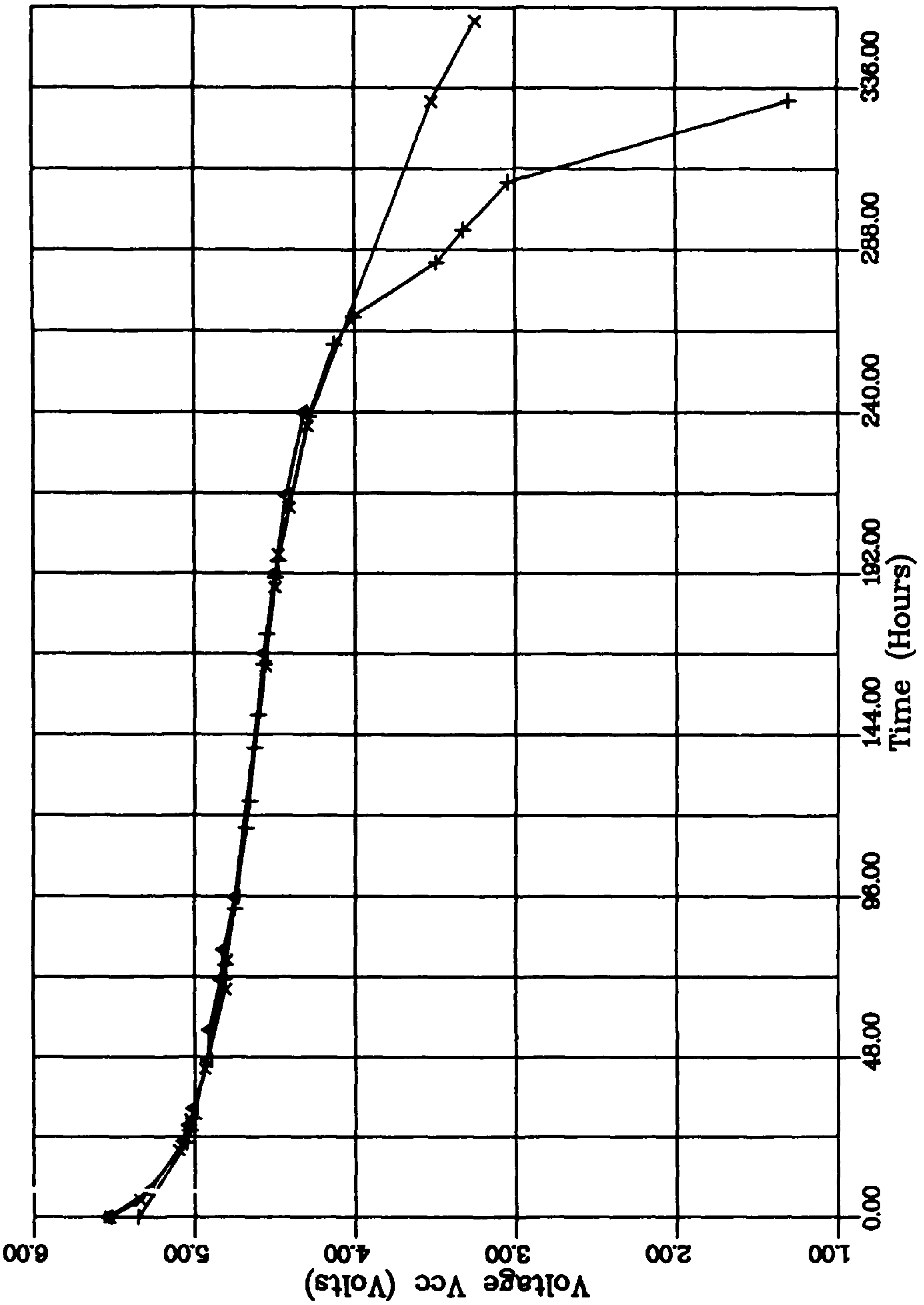
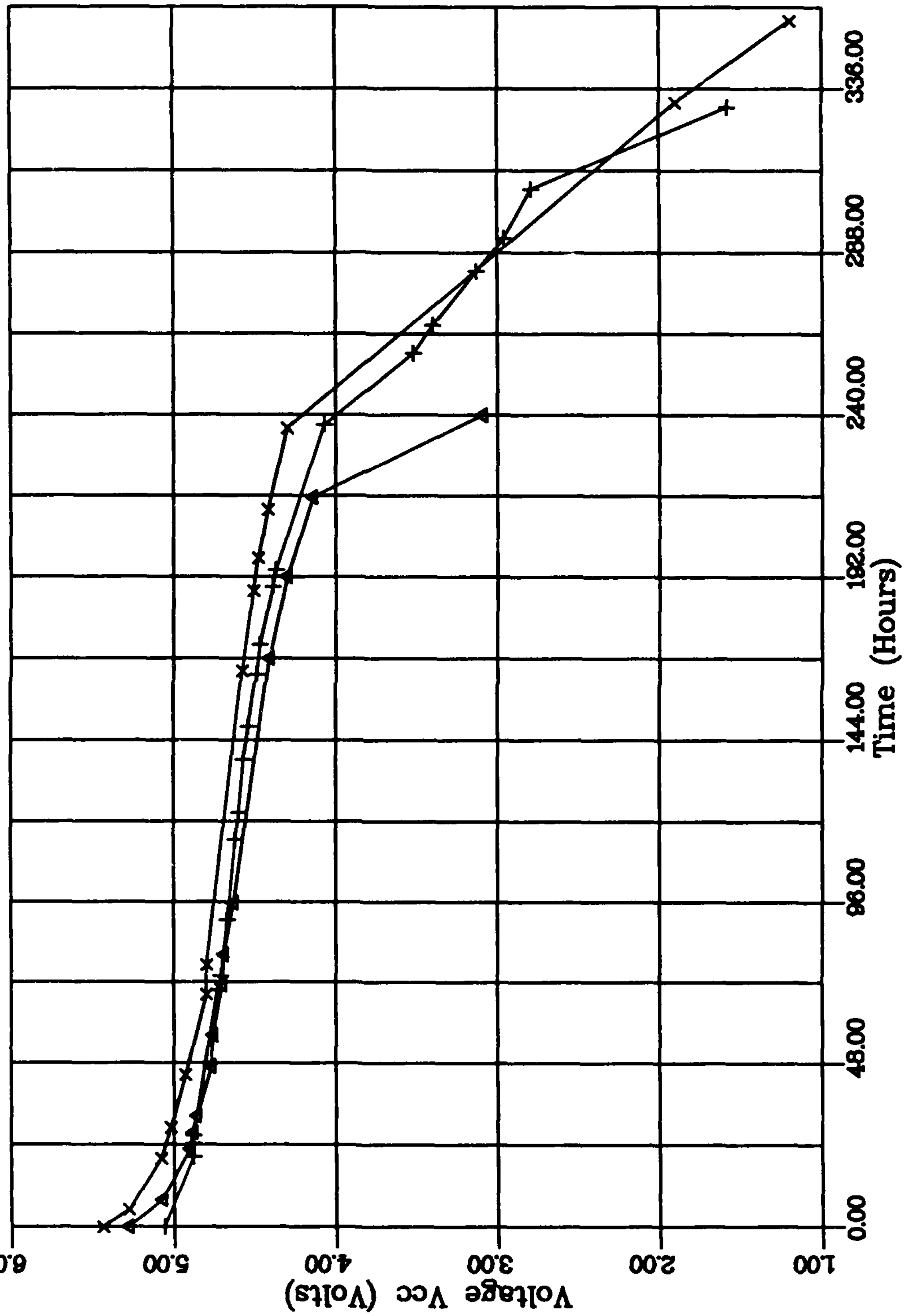


Figure A.6: Mine 9 – Supply Voltage vs. Time



UNIT NUMBER	CURRENT IN V_C BUS (μA)		CURRENT IN V_R BUS (μA)		CURRENT IN E BUS (mA)	
9	8.43	8.	0.0	0.0	13.78	13.76
	8.25	8.13	0.0	0.0	13.7	13.65
8	8.14	8.	0.0	0.0	13.65	13.63
	8.1	8.02	0.0	0.0	13.6	13.4
7	8.97	9.	0.0	0.0	13.76	13.71
	8.61	8.54	0.0	0.0	13.59	14.0
6	9.21	9.	0.0	0.0	13.28	13.22
	9.05	9.10	0.0	0.0	13.2	18.5
3	8.75	9.	0.0	0.0	13.73	13.67
	8.65	8.56	0.0	0.0	13.63	13.5
b	9.67	10.	0.0	0.0	13.29	13.22
	9.47	9.34	0.0	0.0	13.18	13.0
mean		8.75		0.0		13.74
std. dev.		.56		0.0		1.05

Table A.1: Wait for Arm State Quiescent Currents

UNIT NUMBER	CURRENT IN V_C BUS (μA)		CURRENT IN V_R BUS (μA)		CURRENT IN E BUS (mA)	
9	13.67	13.	0.0	0.0	10.44	10.43
		13.4	0.0	0.0	10.38	10.34
8	13.09	13.	0.0	0.0	10.46	10.46
	13.05	12.9	0.0	0.0	10.42	10.3
7	14.20	14.	0.0	0.0	10.48	10.42
	13.73	13.65	0.0	0.0	10.34	10.0
6	14.50	15.	0.0	0.0	9.97	9.93
	14.35	14.25	0.0	0.0	9.90	14.0
3	14.13	14.	0.0	0.0	10.44	10.4
	13.97	13.84	0.0	0.0	10.36	10.2
b	15.68	15.	0.0	0.0	9.95	9.90
	15.38	15.22	0.0	0.0	9.87	9.7
mean		14.04		0.0		10.38
std. dev.		.81		0.0		.81

Table A.2: Countdown to Arm State Quiescent Currents

UNIT NUMBER	CURRENT IN V_C BUS (μA)		CURRENT IN V_R BUS (μA)		CURRENT IN E BUS (mA)	
9	1.63	2.	0.0	0.0	7.78	7.76
	1.8	1.58	0.0	0.0	7.72	7.6
8	1.79	2.	0.0	0.0	7.6	7.62
	1.98	1.81	0.0	0.0	7.95	7.5
7	2.07	2.	0.0	0.0	7.8	7.72
	1.96	1.94	0.0	0.0	7.7	8.0
6	2.13	2.	0.0	0.0	7.29	7.26
	2.07	2.11	0.0	0.0	7.24	10.9
3	1.86	2.	0.0	0.0	7.78	7.75
	1.96	1.98	0.0	0.0	7.73	7.70
b	2.02	2.	0.0	0.0	7.14	7.10
	1.97	1.88	0.0	0.0	7.09	7.0
mean		1.94		0.0		7.70
std. dev.		.14		0.0		.73

Table A.3: Armed State Quiescent Currents

UNIT NUMBER	CURRENT IN V_C BUS (μA)		CURRENT IN V_R BUS (mA)		CURRENT IN E BUS (mA)	
9	1.13	1.	.761	.762	7.22	7.25
	1.9	1.10	.761	.758	7.2	7.15
8	1.32	1.	.75	.751	7.10	7.10
	1.32	1.3	.77	.749	7.06	7.0
7	1.56	2.	.757	.755	7.46	7.39
	1.45	1.44	.752	.753	7.34	8.
6	1.61		.745	.744	6.73	6.71
	1.57	1.54	.742	.743	6.69	10.1
3	1.29	1.	.748	.747	8.14	8.13
	1.26	1.24	.76	.745	8.09	8.0
b	1.39	1.	.766	.764	6.62	6.53
		1.32	.78	.762	6.47	6.5
mean		1.34		.755		7.32
std. dev.		.27		.095		.78

Table A.4: Disarmed State Quiescent Currents

DEVICE	I_{min} (mA)	I_{max} (mA)
processors each	2.75	3.25
magnetometer	.10	2.5
seismometer	.03	.03
op-amp	3.0	3.0
NVRAM	–	–
ADC	1.0	2.0
battery check IC	.02	.04
total	9.65	14.10

Table A.5: E Bus Current Draw

UNIT NUMBER	CURRENT IN V_C BUS (mA)	CURRENT IN V_R BUS (mA)	CURRENT IN E BUS (mA)
9	33.0	601	94.2
8	34.4	571	90.4
7	1.60	589	103
6	2.0	578	162.9
3	.945	602	99.6
b	.027	592	88.3
mean	12.0	589	106.4
std. dev.	16.8	12.44	28.2

Table A.6: Off → Wait State Peak Currents

UNIT NUMBER	CURRENT IN V_C BUS (μA)	CURRENT IN V_R BUS (mA)	CURRENT IN E BUS (mA)
9	29	590	21.9
8	19	562	22
7	20	575	21
6	22	616	30.9
3	22	602	22.1
b	25	594	21.6
mean	23	590	23.3
std. dev.	3.7	19.2	3.8

Table A.7: Wait → Count to Arm State Peak Currents

UNIT NUMBER	CURRENT IN V_C BUS (μA)	CURRENT IN V_R BUS (mA)	CURRENT IN E BUS (mA)
9	22	7	14
8	39	0	11
7	145	0	9
6	391	0	16.0
3	23	0	11.2
b	135	0	10.4
mean	126	1.2	11.9
std. dev.	141.2	2.9	2.6

Table A.8: Count to Arm → Arm State Peak Currents

UNIT NUMBER	CURRENT IN V_C BUS (μA)	CURRENT IN V_R BUS (mA)	CURRENT IN E BUS (mA)
9	19	565	22
8	19	570	22.6
7	25	576	21
6	28	578	34.2
3	22	534	22.6
b	22		
mean	22.5	565	24.5
std. dev.	3.5	17.9	5.5

Table A.9: Arm → Disarmed State Peak Currents

Appendix B
Smoke Charge Tests

Numerous tests were performed on several smoke charges following their delivery. The reasons for these tests were:

1. to ensure that the charges, as a lot, were not defective,
2. to characterize the electrical properties of the squib,
3. to validate the firing chain design, and
4. to determine how the charges function when buried.

To ensure that the entire lot of the charges was not defective, each of the fourteen charges used during these tests eventually was subjected to sufficient current to ensure ignition. If all, or a large proportion of the charges did not go off, then the lot would be assumed to be defective. If all, or a large proportion of the charges did ignite, then the lot would be assumed to be in good working order, even though individual charges within the lot may eventually be found to be defective. In the end, the fourteen charges used here, and others used in other tests or demonstrations of the Practice Mine all ignited, indicating that the lot was not defective.

The electrical properties needing characterization were:

1. the resistance of the squib,
2. the minimum current necessary for ignition, and
3. the time taken for ignition,

The Practice Mine was designed to be emplaced upon the surface or buried under the ground. However, during the design stages, no information was available to suggest how deeply the smoke charge could be buried and still allow the smoke generated upon ignition to escape to the surface. A test was performed to provide this information.

To perform the tests, one of the 200 Practice Mine prototypes was gutted; that is, the electronics and wiring harnesses were removed, along with one of the two windows covering the flip disc displays. The empty case served as a convenient holder for the smoke charge during the tests. Two long lead wires were then attached to the brass contact fingers located at the bottom of the gutted mine's pyrotechnic well and fed out of the mine case through the hole left by the removed window. These brass fingers make contact with the two pins at the bottom of a smoke charge, once that charge has been inserted into the pyrotechnic well. The other ends of the lead wires were connected to a switch box. By simply turning a dial, the configuration of the circuitry within this box could be immediately changed, allowing the tests to be done quickly and easily. Two AA batteries in a separate holder were also connected to the switch box. These batteries were used as the power source to ignite the charges. The terminal voltage of the pair was measured to be 3.03 volts.

When a smoke charge was initially inserted into the gutted mine, the resistance of its squib was measured. To do this, an ohmmeter was placed across the terminal posts where the two lead wires were attached to the switch box. During these resistance measurements, the switch box was configured so that an open circuit appeared across these terminal posts. As a result the resistance measured was of the lead wires and squib only. Prior to the tests, the resistance of the lead wires was measured to be 1.1Ω. The values obtained during this test are shown in Table B.1. These values have been corrected to account for the resistance of the lead wires. The mean value of the squib resistance was calculated to be $1.3\pm0.3\Omega$. During the mine's design stage, the resistance of the squib was assumed to be 1Ω.

To determine the minimum current necessary for smoke charge ignition, a set of current limiting resistances was introduced into series with the smoke charge/lead resistance. The battery pair was then connected to this circuit, and the charge was examined to determine if it ignited. The results of this test are displayed in Table B.2. They suggest that at least 440 mA of current is necessary to ignite the charge. This agrees with the manufacturer's statements. Hands Fireworks has said that 500 mA is necessary to ignite the smoke charge.

A current probe was used in an attempt to determine the time elapsed between start of the ignition current and actual ignition. The probe was clipped to one of the two lead wires and a charge fired. The resulting current-time characteristic was captured and displayed on a storage oscilloscope. After a number of failed attempts, a successful measurement showed that the current rose to approximately 800 mA for approximately 10 ms before the current drops to zero as the squib ignites and becomes an open circuit. This 10 ms value could be used as a limit when determining the distance travelled by a vehicle from the

point where it first sets off a mine to the point where smoke first appears from the mine.

Another test was performed to verify the performance of the fire chain circuitry. This circuitry was designed to minimize the chance of smoke charge ignition in the event of a failure within the mine. (Chapter 7 should be examined for a complete description of the firing chain circuitry). The first part of the test involved the circuit shown in figure 7.4. This configuration of the fire chain circuitry would occur if relays 1 and 2 accidentally close while the Safe/Arm switch is in the Safe position. The charge did not ignite when power was applied to this circuit configuration. The second part of the test involved the circuit shown in figure 7.5. This configuration of the fire chain circuitry would occur if relay 2 accidentally closes while the Safe/Arm switch is in the Arm position and relay 1 remains open. Again, the charge did not ignite when power was applied to the circuit.

The final part of the test involved the circuit shown in figure 7.6. This configuration would occur if relay 1 accidentally closes while the Safe/Arm switch is in the Arm position and relay 2 remains open. This is the only configuration which actually allows current to flow through the squib. This test was performed twice, with the second attempt lasting for more than two minutes. The smoke charge did not fire in either case. This result was not surprising. The current which would flow through the squib is limited by the 40kΩ resistor (shown below RLY 2) to only 75 μA, well below the 440 mA minimum current necessary for ignition found previously. (This charge did ignite later when it was subjected to a 500 mA current). After describing this situation to the smoke charge manufacturer, Hands Fireworks stated that a prolonged 75 μA current flow may burn out the squib without starting the rest of the charge. If this occurs, then the charge could not be ignited at a later time.

The last test involving the smoke charge was done to determine how the charge would act when buried. To perform this test, a smoke charge was buried, then ignited and observed to determine if the smoke appeared at the surface. Three different depths were used; 1.5, 2.5 and 3 inches. The depth was measured from the top of the smoke charge to the surface. The overburden consisted of gravel with a small proportion of soil. In all cases the smoke appeared at the surface. At the shallower depths, the overburden was thrown aside by the pressure of ignition. When the mine was buried deeper, the overburden was not thrown aside; instead, the smoke welled up through the overburden.

In summary, the tests showed the following;

1. the smoke charge lot is not defective,

2. the resistance of the squib is approximately 1.3Ω,

3. the minimum ignition current is 440 mA,

4. the firing chain circuitry performs as expected,

5. burying the mine to a depth of 3 inches is feasible.

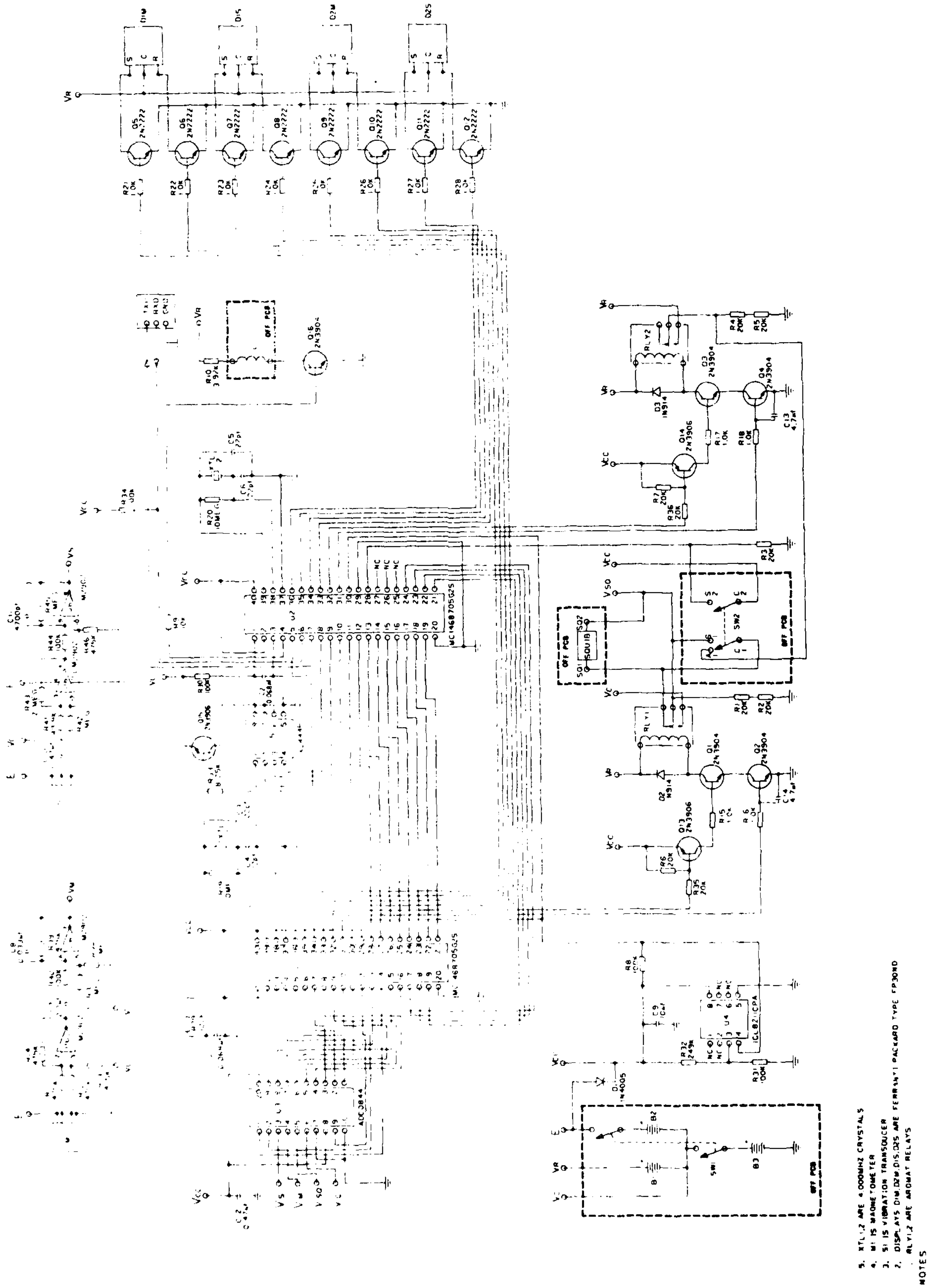
Unit	Resistance Ω
1	1.4
2	1.4
3	1.5
4	1.0
5	1.0
6	1.1
7	1.9
8	1.4
9	1.7
10	0.9
11	1.1
12	1.4
13	1.1
14	1.0
mean	1.3
std. dev.	0.3

Table B.1: Squib Resistance Values

Resistance Ω	Times Tried	Current (mA)	Fired?
100k ±1%	4	.03	none
1k ±1%	4	3	none
100 ±1%	4	30	none
12.5 ±.2	4	242	none
9.3 ±.2	1	325	no
8.5 ±.2	1	356	no
6.9 ±.2	1	440	yes
6.3 ±.2	1	480	yes
6.1 ±.2	1	497	yes

Table B.2: Current Limiting Results

Appendix C
Practice Mine Schematic



PRACTICE MINE SCHEMATIC

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1 ORIGINATING ACTIVITY Defence Research Establishment Suffield	2a. DOCUMENT SECURITY CLASSIFICATION Unclassified 2b. GROUP

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5 AUTHOR(S) (Last name, first name, middle initial)

BERNHARDT, Richard H. and CHESNEY, Robert H.

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13. ABSTRACT

The Ordnance Detection Group of the Defence Research Establishment Suffield has designed an electronically fuzed land mine to be used during training exercises. A description of the hardware within the practice mine is given in this report.

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KEY WORDS

Anti-vehicle

Mine

Fuzing

Training

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